THE IMPACT OF ENERGY MARKETS ON THE CANADIAN FOOD WHEAT SUPPLY CHAIN

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By

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ABSTRACT

Rising oil prices have been a concern for both developed and developing countries, especially in more recent years as it tends to have a crippling effect on production and transportation. Many countries have moved towards the development of fossil fuel alternatives as a means of achieving energy independence and achieving environmental targets (for example the Kyoto Protocol). Developments in both these types of energy markets (fossil fuel and renewable fuels) may impact Canadian Prairie agriculture.

Most of Canadian prairie crops are exported. The Canadian prairies are land locked to some extent. The closest ocean access to the eastern portion of the prairies is the port of Churchill, but is closed during the winter season. Crops are therefore transported west through the Rocky Mountains or east through the Great Lakes to get to a port. This requires hundreds of kilometres of truck and rail transportation, which is fuel dependent. To a lesser extent, at the micro-level farmers depend on fossil fuels to operate machinery to facilitate efficient crop production. If oil prices continue on an upward trajectory, will farmers cropping behaviour change?

Furthermore, the development of the bioethanol industry on the Canadian prairies has given wheat farmers another crop option. As oil prices increase, the price of ethanol increases as well. Also, demand is bolstered by renewable fuel standards and government tax exemptions or subsidies.

This study seeks to put forward the notion that as oil prices increase, crop production and transportation costs also increase thereby reducing farmers' gross margins. Also, *ceteris paribus*, as oil prices increase there will be an increased demand for, and an increase in the price of biofuels thereby increasing the price of biofuel feedstock. Higher feedstock prices are expected to increase the gross margins of farmers. Therefore higher oil prices drive increased crop competition between traditional cropping (cropping for food exports) and energy cropping.

This thesis seeks to ascertain at what level of oil prices would farmers, in general, be willing to switch from producing wheat for traditional (hard/food wheat) purposes to bioenergy (soft/ biofuel wheat) cropping alternatives. Also under varying scenarios of oil price growth and

government support to the biofuel industry, this thesis seeks to ascertain the impact of biofuel industry expansion on grain elevator pricing behaviour and the structure of the elevator industry, assuming elevators spatially compete with each other for farmers' crops.

An agent based model (ABM) is employed for this study. The model is selected over other types as the researcher wants to capture the increased complexity stemming from the competition between crops that belong to at least one distribution chain. Agent based networks allow for emergent behaviour that is obtained from the spatial competition of elevators. Finally, the agent based model allows for spatial heterogeneity in location of farmers in terms of soil quality and their proximity to an elevator, which affects crop productivity and transportation costs, respectively.

The ABM (also called the *FARMCHAIN* model) is comprised of over 35000 farmer agents, 176 elevator agents, 6 canola crushing plant agents, 5 ethanol plant agents and 1 biodiesel plant agent located on the 20 census agricultural regions (CARs) of Saskatchewan. Farmers allocate land based on their expected gross margins. Farmers produce and truck crops to the designated distribution chain. Crops move through the chain and at every stage the associated costs are computed and apportioned to the farmer. At the end of the period, gross margins are computed and these gross margins are used in computing the expected gross margins for the subsequent period.

It is found that real annual crude prices would have to be greater than $133 before farmers begin to switch to producing biofuel wheat (soft wheat) from food wheat (hard wheat). This would have to be approximately 30% higher than that of 2008 in which crude prices were at record levels. Also, if biofuel support is declining then it would take a considerably higher price to entice farmers, in aggregate, to switch.

ACKNOWLEDGEMENTS

I would like to thank first of all, the Creator who gave me the strength to persevere to the end of this process. I would also like to thank my wife, who has been a tower of support throughout this thesis process. I would also like to thank my mother for her prayers and words of encouragement.

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1.1 Background and Introduction

While energy markets have held the world stage for a number of years through restricted supply and price spikes (Johnson, 1981; Norton, 1988; Hamilton, 1996; Le Blanc and Chinn, 2004; Vielle and Viguier, 2007), more recent concerns about food adequacy and sovereignty have arisen from the fact that high oil prices have driven the development of renewable fuel technology which has led to a significant reallocation of food supplies to energy production (Brown and Funk, 2008). In addition, more recent concerns of global warming and political turmoil in the Middle East and Africa (Barsky and Kilian, 2004) have prompted the development of renewable energy and have indirectly exacerbated food adequacy and sovereignty concerns.

These developments in the energy markets may have important implications for Saskatchewan agriculture from two perspectives. Firstly, as energy prices increase, so does the return to growing energy crops, and therefore, farmers are faced with the decision to allocate land to traditional crops (such as wheat for food, canola, barley, field peas etc.) as opposed to energy crops. Secondly, higher energy prices increase production and transportation costs of export crops, which dominate Saskatchewan cropping agriculture. This in turn reduces the returns to crop farming and more specifically, traditional crop farming.

Although energy prices may have a direct impact on crop production through the use of fuel to operate farm machinery, energy prices may impact Canadian prairie agriculture indirectly as well. Prairie export crops are at the start of a long supply chain that begins with bulk agricultural commodities that are transported over road, rail, lakes and oceans to diverse demand points. Therefore, energy prices are not only an important input to crop production, but can be of equal importance to other components in the distribution chain. Thus it is not only important to assess the vulnerability of crop production to changes in energy prices but to assess the impact on the supply chain as a whole.

In a context of volatile energy prices and governments' increasing concern about clean and sustainable energy, there has been a significant increase in demand for fossil fuel alternatives within the past decade. This has been made manifest in the implementation of increased biofuel mandates by many countries (Gorter and Just, 2009), which has in turn fostered growth and developments in both bioethanol and biodiesel production. However, many of the biofuel alternatives may compete directly or indirectly with food. Therefore, the impact of world energy prices and domestic bioenergy markets on Canadian crop production may introduce potential temporal feedbacks between food crop and biofuel crop production. This thesis focuses on the effect these changes will have on Saskatchewan's crop production and on the grain elevator industry.

In Saskatchewan, the cropping decisions of farmers have evolved from the wheat-barley-canola dominance in the 1980's to canola-wheat-dry pea dominance in 2010 (Saskatchewan Ministry of Agriculture, 2012). Within the past 10 years there has been a significant increase in the percentage of land seeded to canola with corresponding declines in the percentages for wheat and barley. The increase in canola acres occurred in a context in which farmers were reducing acres of summerfallow land to seed more canola (Gusta, Smyth and Belcher, (2011). Relatively higher canola prices and benefits stemming from innovations made in the adoption of herbicide tolerant varieties have prompted the push toward a greater seeded area (CCC, 2012a; Gusta *et al.*, 2011). Thus any analysis of wheat production must also take into account other potential competing crops such as canola. Canola, like wheat, has multiple end-uses which not only includes the export of the oil, seed and meal but also domestic biodiesel production. Thus an increased demand for biofuels may also have implications for canola cropping decisions as producers in the sector may divert from canola for food towards canola for biofuel (not specifically explored in thesis). Similarly, increased ethanol demand may also shift wheat production from food to biofuel purposes, generating downstream implications for the other participants of the food wheat supply chain.

1.2 Problem Statement

The two competing end-uses for farmland raise questions surrounding the feedback link between land allocation decisions and world oil prices. Higher oil prices increase the demand for biofuels (renewable energy) and the associated derived demand for the feedstock crop which can be produced instead of traditional crops. This thesis seeks to provide an answer to the following questions: 1) what are the linkages between the world crude oil price and the cost of production and transportation of wheat grain and how important are these linkages?; 2) at what level of world crude oil prices will farmers' cropping behaviour change? More specifically, at what level of world crude oil prices would farmers adjust their crop rotations away from food wheat production into the production of industrial wheat for energy purposes?; 3) will changes in cropping decisions influence the level of competition between grain elevators?; 4) in a context of high world crude oil prices, would changes in government support to the biofuel sector influence farmers' production of industrial wheat for energy instead of wheat for food? and 5) if grain elevators are spatially competitive, what are the likely resulting impacts on the competitive structure of grain handling industry of increased oil prices and sustained government support to the biofuel industry?

1.3 Study Objectives

This study has three main objectives:

1. Identify the significant linkages between fuel prices, land use and wheat production for Saskatchewan crop farms.

2. Determine the price that world crude oil prices must exceed before farmers are enticed to allocate most of their land to energy crops.

3. Assess the scenario-based impacts of government biofuel policy and increased oil prices on crop land allocation decisions of farmers and food wheat grain-handling industry structure and competition.

1.4 Scope of the Study

This thesis focuses on crop supply chain modelling. This falls within the larger area of energy-related agent based modelling. This is an area that has been receiving attention in recent times and is likely to be important in understanding the recent shifts in crop production and the food supply chain. According to Scheffran (2009), growing demand for biofuel has implications for land allocation. Based on this, this thesis explores the specific area of land use allocation and its impact on the food supply chain in Saskatchewan and where possible, makes projections for possible land allocation in Saskatchewan and its effects on elevator pricing behaviour. Other potential causes of structural change based on changes in technology such as those studied by Freeman (2005) and Stolnuik (2008) fall outside of the immediate scope of this work and while they may be mentioned, they will not be developed in this work.

1.5 Methodology

This thesis utilizes an agent based simulation model approach to dynamically simulate individual farmer land use decisions in Saskatchewan in response to varying energy prices and government program polices. Farmers utilize a four-crop rotation consisting of wheat, canola, barley and field peas with allocations representative of their corresponding Census Agricultural Region (CAR). Two of the crops are potential bioenergy crops: wheat and canola. Although a hard wheat crop that fails to meet the premium quality grade is often redirected to biofuel purposes or animal feed purposes, it is assumed in this thesis that wheat farmers decide whether to seed hard wheat (wheat for food) or soft wheat (assumed to be used for biofuel production) ex ante and there is assumed to be no ex post redirection of the hard wheat varieties. Each Saskatchewan farm is treated as an individual agent and is located on a simplified landscape with associated cost and production coefficients, according to one of the 20 CAR land use profiles.

A time series of crop prices is dynamically generated using historical distributions. Various scenarios of crop prices, energy prices and government programmes are generated and the aggregate production response of farmer agents and the resulting competitive response of elevator agents are observed. Farmer agents respond to changing prices as increasing fuel prices directly decrease gross margins through their impact on input costs and in farmgate prices through increased transportation costs. Simultaneously, increasing fuel prices increase returns to biofuel production thereby increasing the returns to cropping the biofuel feedstock. Since land use decisions are assumed to be based on expected gross margins driven by farmgate returns of the previous period and the following year's price, a change in gross margins may generate changes in land use patterns. Because of the unfolding nature of the individual reactions and behaviour, the simulations are based on 15 periods, with the first four periods being used as initialization periods. In addition, because of the stochasticity of prices, each scenario is replicated 50 times. The agent based model is coded in Netlogo ©, a Java based software.

1.6 Organization of the Study

This thesis commences in the next chapter with a review of the literature, which is comprised of discussions on recent trends in fossil fuel markets, the current structure of the Canadian crop supply chains, inter-linkages between fossil fuel and agricultural markets, vertical markets and competing supply chains, and literature concerned with the modelling of farmers' decision behaviour. Chapter 3 focuses on describing the agent based framework utilized in this study by identifying the roles of, and the relationships between, agents and the inter-temporal transitions of the agent based simulation model, called the *FARMCHAIN* model. Chapter 4 discusses the data used to initialize and parameterize the *FARMCHAIN* model. In Chapter 5 the verification and validation of the *FARMCHAIN* model is presented. Also, the results of the model are discussed in Chapter 5 while Chapter 6 summarizes and concludes.

CHAPTER 2: REVIEW OF LITERATURE

2.1 Trends in Fossil Fuel Demand, Supply and Prices

The topic of sustainable energy has received considerable attention in both the media and academic literature (Chase-Dunn, 2002; Goldemberg, 2007; Lund, 2007) over the past four decades. This literature arises out of a context of significant fluctuations in fossil fuel prices (Short, English, and Heady, 1984; Saghaian, 2010), which are due in part to the underlying movements in the related economic variables of demand and supply. Over the past decade, developing and emerging countries have increased their consumption of fossil fuels but the growth in supply has been relatively constrained due in part to nature of the industry. Industry supply is characterized by cartel behaviour (Kranser, 1974; Mead, 1979) which means that suppliers can influence world price by restricting supply. Furthermore, significant time lags involved in exploration, litigation, capital sourcing and drilling can also account for longer than usual cycles in price fluctuations (International Monetary Fund, 2011).

The decade commencing in the year 2000 was fraught with significant volatilities in fossil fuel prices. Average North American crude oil prices peaked in July of 2008 at approximately $846 per cubic meter or $134 per barrel (NRCAN, 2011a). As a consequence, the year-on-year increase in the average North American crude oil prices was 41.5%. This marked the second time within a decade in which the year-on-year increase in the average crude price exceeded 40%. The year-on-year increase in 2000 was at 55.4% (Figure 2.1).

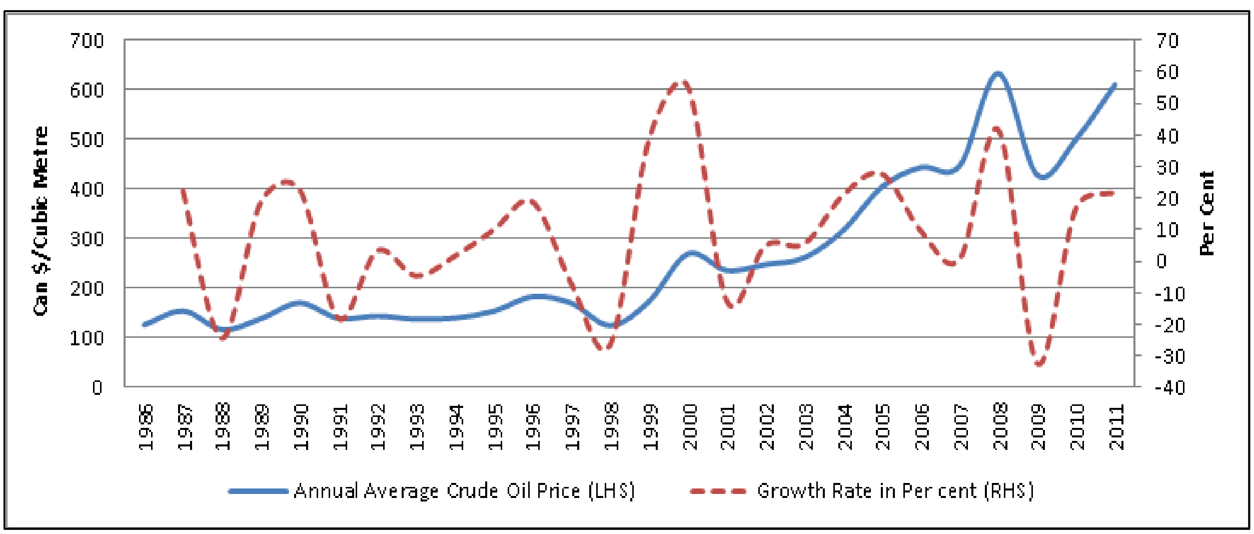

Figure 2.1: North American Average Crude Oil Prices, 1986-2011.
Source: Natural Resource Canada, 2011

The significant increase in crude oil prices over the past decade occurred in a context of strong growth of emerging economies (Hicks and Kilian, 2009). China's annual average Gross Domestic Product (GDP) growth rate per capita was 9.6% over the period 2000-2010. Over the same period, Brazil, India, Indonesia, Russia all had growth rates in excess of 2% while the lacklustre growth rate of the United States was 0.94% (The World Bank, 2011). As these emerging economies grew, their demand for fossil fuels increased. China was the fourth largest importer of oil in 2008, importing roughly 4.4 million barrels per day (Central Intelligence Agency, 2009). China's demand for fossil fuels grew at an annual average rate of 5.6% over the period 2007-2010 whereas the United States' demand declined at an annual average 1.9% (Figure 2.2) over the corresponding period (Energy Information Administration, 2011).

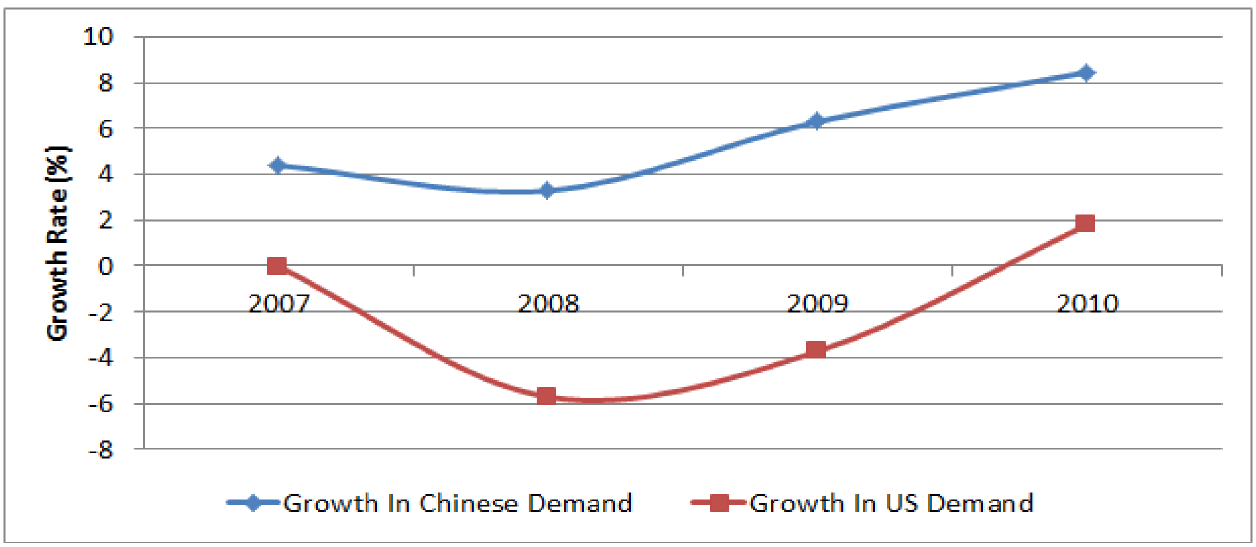

Figure 2.2: Comparison of Growth in Oil Demand of China and the United States
Source: Constructed by author with data from Energy Information Administration, 2011

Annual growth in the world supply of oil fluctuated around a mean of 0.4% over the period 2007-2010. Expansion in the number of drill sites in the United States has been delayed due to the increased political pressure from environmental concerns arising from spills from offshore drilling sites and air pollution (Holing, 1990; Environmental Protection Agency, 2011). In the 1990's most of the regulatory guidelines pertaining to offshore exploration and drilling were either introduced or revised (United Nations Environment Programme, 2001). These guidelines in turn could have led to unexpected increased costs and could have contributed to the sluggish or delayed reaction in supply to increased demand for oil, resulting in longer than usual cycles and significant price increases. With increasing world demand for fossil fuel and lagging supply, there is considerable pressure for increased prices which has impacted agriculture.

2.2 The Impact of World Crude Oil Markets on Agriculture

The literature on the economic impact of energy markets on agricultural markets has been extensively researched over an extended time period. Many have studied the impact of the nature of the industry on prices, macroeconomic stability and the impact on agriculture (Short *et al.*, 1984; Moosa, 1993; Ball, 2006; Fabiosa, 2009; Saghaian, 2010). The analyses have ranged from the discussion of the Dutch Disease - the indirect impact of increased oil prices on exchange rates that caused a loss in competitiveness in the agriculture sector in the Netherlands (Feltenstein, 1992) to econometric estimations of relationships between crude oil prices and agriculture commodity prices (Fabiosa, 2009; Saghaian, 2010). This section gives a brief overview of some of this literature.

There have been three notable spikes in oil prices in the post-World War II era: the first in the 1950's; the second occurred in the period of 1973-74; and the third began in 2004 (Radetzki, 2006) and ended in 2008 (Hicks and Kilian, 2009). Radetzki also highlighted the relationship between these price booms and the growth rate of developed countries. More specifically, he noted that periods of price spikes are preceded by periods of significant increases in economic growth and that the end of every price boom is accompanied by significant declines in the GDP growth rate of countries (Radetzki, 2006). He also highlights the fact that the third price boom was more prolonged than the first two price booms and notes that all three price booms are a result of changes in demand-side variables. The recent vicissitudes in oil prices have been driven primarily by increased scarcity and developing country growth (IMF, 2011). Fabiosa (2009) noted that the most recent price boom has been characterized by an increased drive for fuel alternatives in the form of biofuels and has in turn led to increased integration between energy and agricultural markets. Furthermore, Baffes and Haniotis (2010) noted that the significant link between energy and non-energy markets will continue to be the leading factor that influences commodity prices and more specifically food prices.

Fabiosa (2009) utilized a correlation assessment of oil prices on the livestock sector to bifurcate the study sample into two specific time periods: a ‘pre-ethanol boom’ and an ‘oil-linked, post-ethanol boom’ demarcated by the periods 1992-2004 and 2005-2008, respectively. He found that there is a significant increase in the correlation between oil prices and grain markets in the post-ethanol boom period versus the pre-ethanol boom period from 0.02 to 0.89. It is therefore concluded that biofuels have created the link between energy markets and agricultural commodity prices.

2.3 Canadian Prairie Crop Production, Competition and Distribution

While crop land use has evolved over time, it has more recently changed as a result of considerable increases in some crop prices, in production technologies and in energy costs. At the farm level, optimal cropping patterns are a function of relative prices and gross margins (Gardener, 1975). However, because the efficiency of the logistical chain impacts the transmission of information such as prices, competiveness can be regarded as a competition between the distribution chains of alternative crops. The following sections discuss the nature of changes in cropland allocation as well as the evolution of world prices. Thereafter the structure of the food wheat, barley, canola and field pea distribution chains are discussed followed by briefly highlighting the impact fuel price has on crop production and crop distribution and finally, competition and coordination of vertical markets is examined.

2.3.1 Land Allocation, Production and Export of Crops

In 2006, the four most seeded crops in the Saskatchewan were spring wheat, canola, barley and durum with seeded acres of 9.6 million, 6.0 million, 3.5 million and 3.2 million, respectively (Figure 2.3). In the following five years, farm cropping decisions have changed significantly in that farmers significantly increased their acreage allocated to canola and lentils and simultaneously reduced the acreage alloted to spring wheat, barley and durum. Farmers only marginally increased the amount of land alloted to dry peas. At end the end of 2010, the four most seeded crops are canola, spring wheat, lentils and dry peas with 7.8 million acres, 7.4 million acres, 3.3 million acres and 2.8 million acres, respectively.

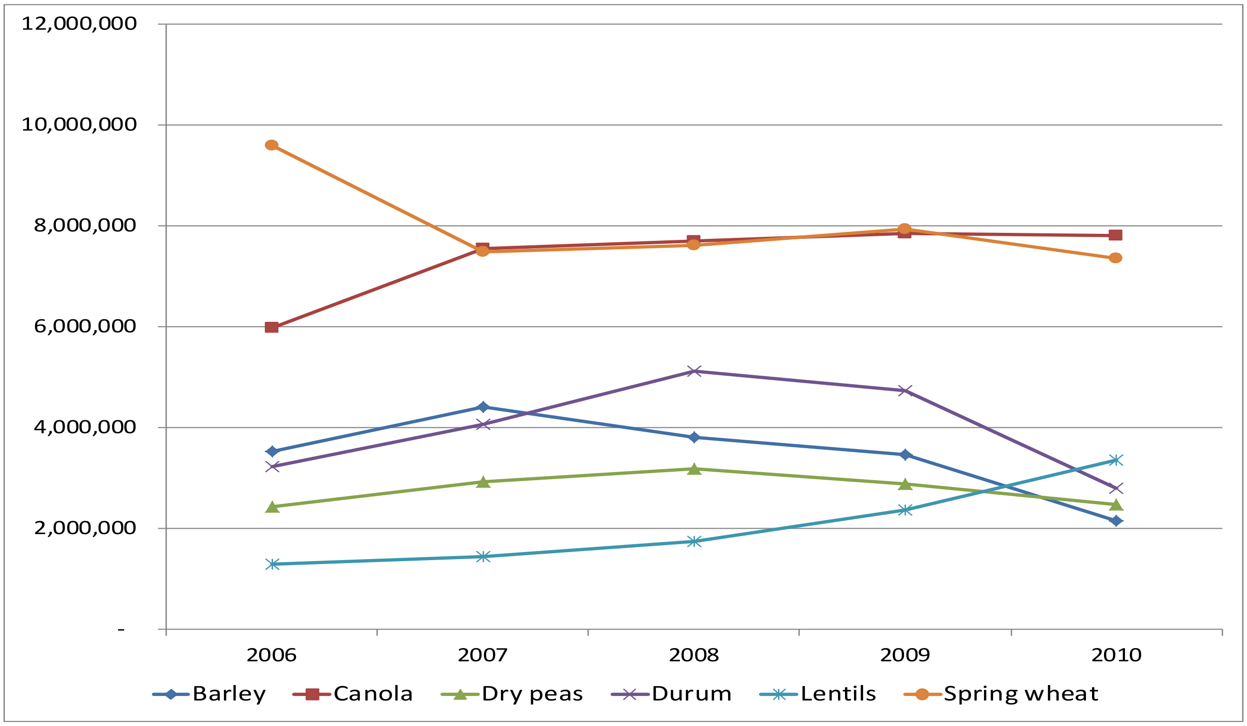

Figure 2.3: Total Seeded acres in Saskatchewan of the six most seeded crops, 2006-2010.
Source: Government of Saskatchewan Ministry of Agriculture (2012)

Figure 2.4 shows the spatial extent to which the six most seeded crops in Saskatchewan are planted in each of the 20 Census Agricultural Regions (CARs) in 2010. The seeding of spring wheat is significant in all CARs. Canola is most prevalent in the northern and central parts of the CARs (CARs 5- 9). Durum is seeded mostly in the south-west portion of the province. Barley, although seeded in relatively small proportions is represented most in the central and northern CARs. Land allotted to dry peas is also comparatively small and there is no discernible seeding pattern in the geographical extent (Figure 2.4).

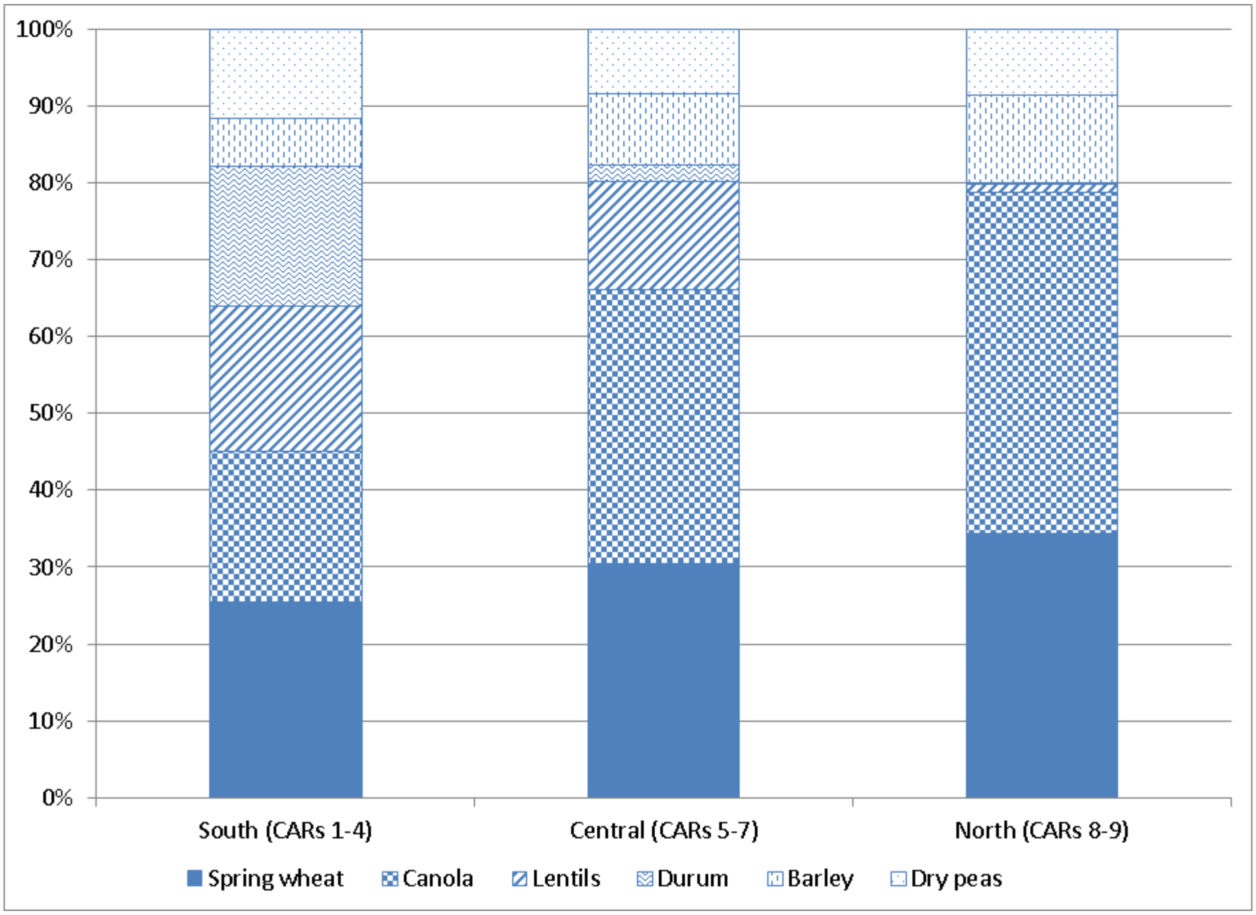

Figure 2.4: Seeded acres of the six most seeded crops in Saskatchewan in 2010 by CARs.
Source: Government of Saskatchewan Ministry of Agriculture (2012)

Although durum is a crop that is extensively seeded in the province, the spatial distribution is skewed towards the southern part of the province. For privacy concerns, statistical CAR data are suppressed for CARs 2a, 4a, 7a, 8a, 9a and 9b, indicating few respondents. Since CAR-specific information is needed for this study, durum is excluded from the analysis. Despite the strong growth in the number of acres allotted to lentils over the period 2006-2010, CAR specific information for CARs 1b (all 4 years), 5b (in 2006 and 2007), 9a (in 2007), 9b (all 4 years) is restricted due to the lack of spatial prevalence in the seeded crop across the province in the 4 years prior to 2010. Therefore the lentil crop will be excluded from the analysis. As a result, approximately 66.0% of total seeded crop acreage in the province is accounted for by these four crops.

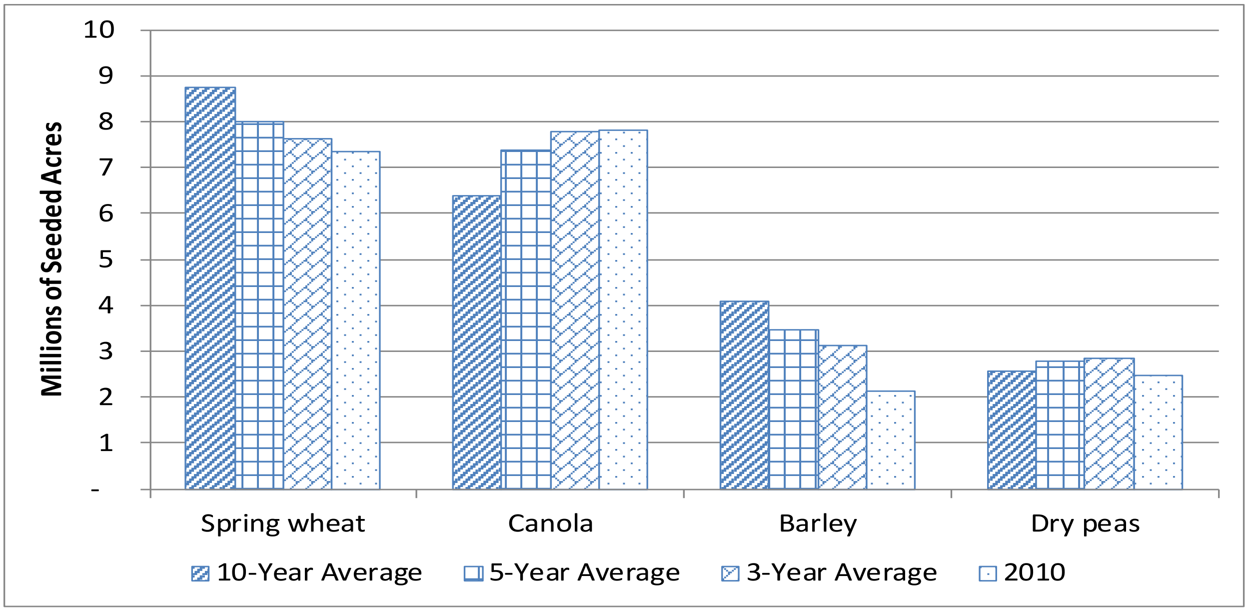

Figure 2.5: Average seeded acres over 10 years, 5 years, 3 years and in 2010 in Saskatchewan of spring wheat, canola, barley, dry peas.
Source: Government of Saskatchewan Ministry of Agriculture (2012)

It is evident from Figure 2.5 that there exists a pattern in Saskatchewan farmers' cropping decisions for the four crops chosen for the analysis. The land allocated to spring wheat and canola is consistently greater than that of barley and field peas. While wheat and barley allocations progressively decline, canola increases over time. The actual land allocation ouctome in the form of production levels are, however, not as distinct as yields varying from year to year and acts of nature or other uncontrolable factors may influence crop production..

To illustrate the varying production yield, It is shown in Figure 2.6 that production in 2010 was lower than the 10-year, 5-year and 3-year historical averages in spring wheat, barley and dry peas. In contrast, Saskatchewan's 2010 canola production was higher than its 10-year and 5-year historical average but lower than its 3-year historcal average. Its is also evident that over the 10-year period barley was most stable (Figures 2. 6). Compaaring figures Figures 2.5 and 2.6, it can be seen that barley and pea production were most consistent with cropland allocations.

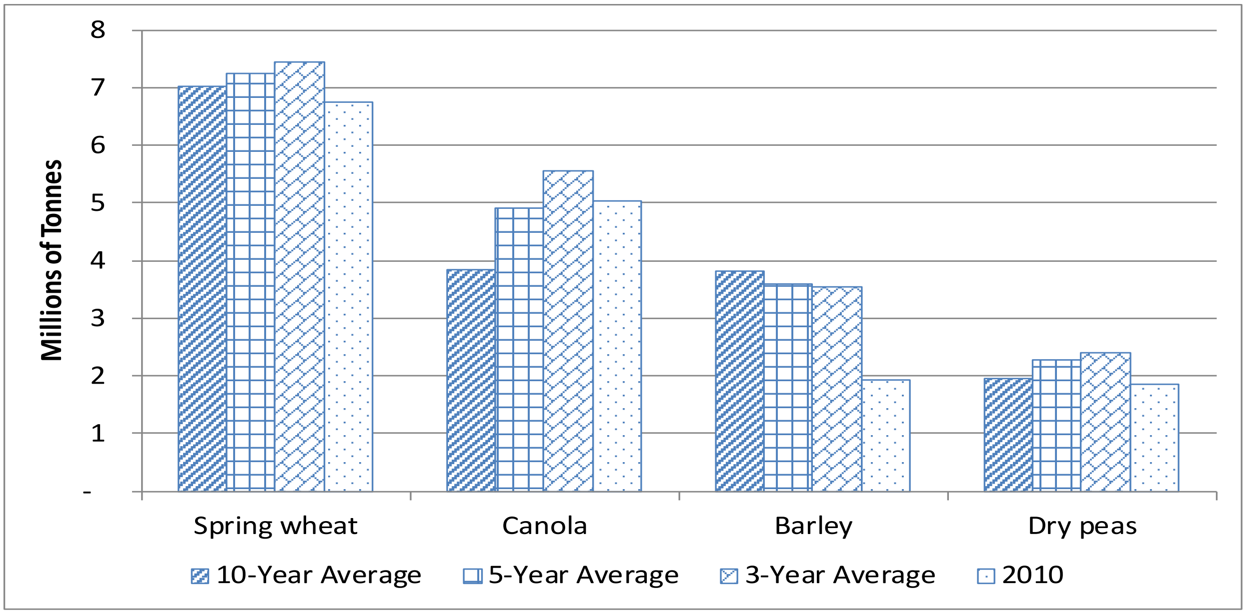

Figure 2.6: Average production over 10 years, 5 years, 3 years and in 2010 in Saskatchewan of spring wheat, canola, barley, dry peas.
Source:Government of Saskatchewan Ministry of Agriculture (2012)

On the international scale, Canada is on average, the sixth-largest producer of wheat in the world; producing an average of 24.7 million metric tonnes per year over the past four crop years commencing 2007/08 (Table 2.1). Canada's production over this time period represented approximately 18.1% of the average production of the 27-member European Union - the largest producer. However, Canada is the third largest exporter of wheat (Table 2.1).

Table 2.1: The World Top 10 Wheat Producing and Exporting Countries

Production			Exports			
Rank	Country	2007-2011 Average (000's of Tonnes)	Rank	Country	2005-2009 Average (000's of Tonnes)	Market Share (%)
1	EU-27	136,420	1	EU	37,233	28.2
2	China	113,016	2	United States	27,108	20.5
3	India	78,965	3	Canada	17,007	12.9
4	United States	61,077	4	Australia	13,876	10.5
5	Russia	54,103	5	Russia	12,602	9.5
6	Canada	24,670	6	Argentina	8,733	6.6
7	Pakistan	23,039	7	Ukraine	6,426	4.9
8	Australia	20,728	8	Kazakhstan	4,090	3.1
9	Ukraine	19,383	9	Mexico	807	0.6
10	Turkey	16,938	10	China	769	0.6

Source: Constructed by author with data from FAO-STAT, 2012 and Production Supply and Disposition (PS&D), 2012

Over the period 2005-2009, Canada exported approximately 17.0 million tonnes of wheat per year or 12.9% of the world export market. Furthermore, Canadian wheat exports exhibited a trend increase over the four crop years commencing in 2007/08. Exports were 12.2 million tonnes in the 2010/11 crop year, a year-on-year increase of 1.6 million tonnes. Furthermore, the 10-year moving average ending in the years declined over time (Table 2.2).

Table 2.2: Canadian Wheat Exports 2005/06-2010/11

Crop Year	Total Exports ('000 Tonnes)	10 year Moving Average ('000 Tonnes)
2005/06	10,607	12,161
2006/07	14, 024	11832
2007/08	11,851	10272
2008/09	14,109	9,204
2009/10	14,002	11,744
2010/11	12,217	11,659

Source: Canadian Grain Commission Canada Grain Exports Crop Years (2005/06-2011/12)

Canada was the second largest producer of canola in 2010, producing 11.8 million tonnes, behind China which produced 13.1 million tonnes but ahead of India which produced 6.4 million tonnes. Canada was the number one producer of dry peas in the world in 2010. Canada was the sixth largest producer of barley in 2010. Barley production is dominated by European countries (Table 2.3).

Table 2.3: The World Top 10 Canola, Dry Peas and Barley Producing Countries in 2010

	Canola		Dry Peas		Barley	
Rank	Country	Production ('000 of Tonnes)	Country	Production ('000 of Tonnes)	Country	Production ('000 of Tonnes)
1	China	13,082	Canada	2,862	Germany	10,412
2	Canada	11,866	Russia	1,218	France	10,102
3	India	6,410	France	1,098	Ukraine	8,485
4	Germany	5,698	China	991	Russia	8,350
5	France	4,816	India	700	Spain	8,157
6	U.K.	2,230	U.S.A.	645	Canada	7,605
7	Australia	2,181	Ukraine	452	Australia	7,294
8	Poland	2,078	Australia	280	Turkey	7,240
9	Ukraine	1,470	Ethiopia	232	U.K.	5,252
10	U.S.A.	1,114	Spain	194	U.S.A.	3,925

Source: Constructed by author with data from FAO-STAT (2012)

For the calendar year 2011 Canadian rapeseed seed exports were 7.9 million tonnes, an increase from 2.2 million tonnes in calendar year 2002 (CCC, 2011b). [1] Canadian exports of dried peas increased by 55.3% to 2.5 million tonnes for the August 2010- July 2011 crop year relative to the previous crop year (CGC, 2011). On the other hand, Canadian barley exports declined marginally by 42,000 tonnes to 1.3 million tonnes in the crop year 2010/11 relative to the previous crop year.

The analysis of farmer land allocation, production and exports indicated that farmers were incrementally adjusting crops acreages that Canada is deemed to have a significant market share. Canada is a significant exporter in the rapeseed market and producer in the field pea market; this may be as a result of the relatively favourable agronomic conditions for these crops that exist on the Prairies and the relatively high market prices.

2.3.2 Saskatchewan Crop Prices 2001-2010

The changes manifested in farmer land allocation over the past decade occurred in a context of relatively higher canola and field pea prices (Figure 2.7). Over the period 2001-2009, the average annual prices of canola and field peas were approximately 1.8 times and 1.5 times, respectively, higher than that of wheat while the average annual price of barley was approximately 94% of average annual price wheat (UN Comtrade, 2012; FAO-STAT, 2012). Price changes can alter farmers' cropping decisions (Walsh, de la Torre Ugarte, Shapouri, and Slinsky, 2003). However, farmers' cropping decisions may also be influenced by the structure of the crop distribution chain.

[1] The FAO-STAT database reports comparable trade data within a calendar year and makes the necessary adjustments for discrepancies such as time lags and place of origin/destination inconsistencies.

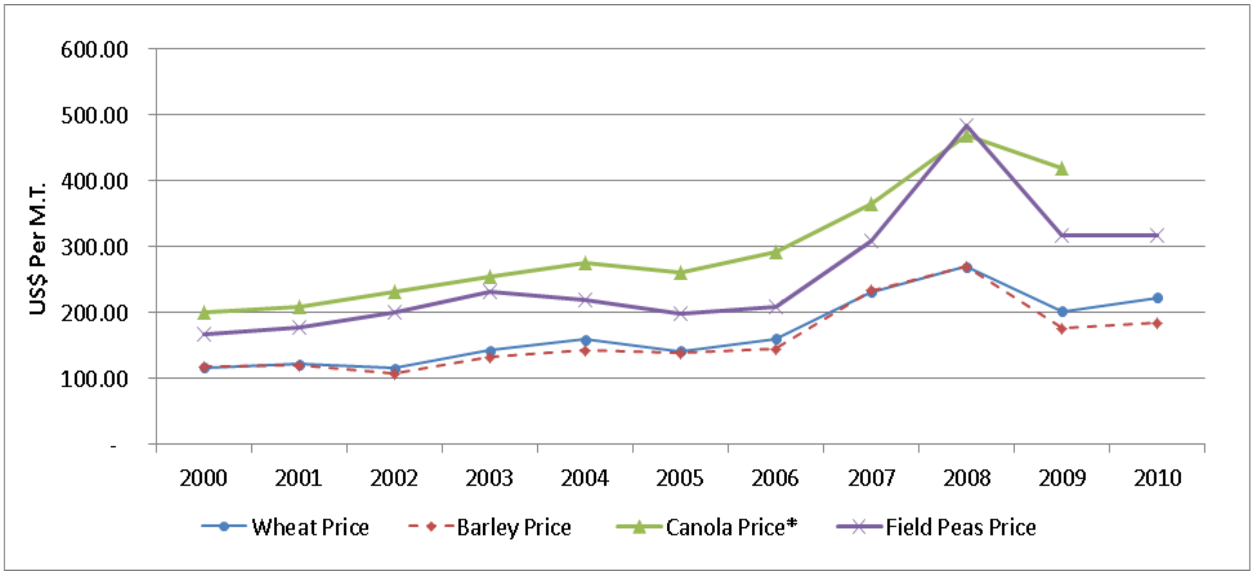

Figure 2.7: Nominal World Crop Prices (1991-2010).
Source: UN Comtrade, 2012 and FAO STAT, 2012 *Canola Source: FAO STAT Constant 1991-2001 Prices.

2.3.3 Saskatchewan Crop Supply Chain

This section briefly discusses the structure of the supply chains for wheat, barley, canola and field peas in western Canada. For each chain the participants are highlighted and the distribution channel discussed. Wheat and barley supply chains are discussed together while canola and dry peas supply chains are discussed thereafter.

2.3.3.1 The Canadian Wheat and Barley Supply Chain

The Canadian food wheat and barley supply chain is comprised of famers, grain elevators, trucking, railway and shipping companies.[2] Producers are a vital component of the wheat supply chain. In 2011 15,634 farms reported seeding wheat in Saskatchewan, down from 21,455 in 2006 (Statistics Canada, 2012). Also, in 2011, 5648 fewer farmers reported seeding barley relative to 2006. In 2011, the number of farmers who reported seeding barley is 8,380. The greatest decline

[2]Historically, the Canadian Wheat Board (CWB) was the only buyer of Canadian wheat, durum, non-feed barley and feed wheat for export (Schmitz and Furtan, 2000). The CWB was responsible for moving the grain from grain elevators through ports and to customers abroad. The claim of the CWB was that it could extract premiums in excess of the world price from the world market (Informa Economics, 2008). The CWB monopsony power was deemed too restrictive and the Government passed Bill C-18 dubbed "Freedom of the Grain Farmers Act" which rendered sales by farmers to the Canadian Wheat Board as voluntary as of August 1, 2012 (Bill C-18, 2011). The CWB had an important impact on the distribution of grain through their ability to sell grain in different markets and extract premiums in excess of world price which in turn translated to higher returns was a claim of many who stood in support of the continued operation of the CWB. It was therefore imperative to assess whether there exists a relationship between wheat premiums earned and the export quantity supplied. Table B-14 in Appendix B shows the data collected to determine if there is a relationship between premiums earned and the quantity supplied. Table B-15 of Appendix B shows that there is no discernible relationship between wheat premiums and export quantity supplied to Japan. Insufficient data are available to reliably estimate the relationships between premiums earned in and quantities supplied to the Colombian market.

in the number of farmers who reported seeding spring wheat is found in CAR 2a; a decline of 43.3% to 387 in 2011 relative to 2006 (Table 2.4).

Table 2.4: Comparison of the Total Number of Farms that Reported Seeding Wheat and Barley in 2006 and 2011

CAR	Spring wheat			Barley			CAR	Spring wheat			Barley		
	Number of farms reporting		%	Number of farms reporting		%		Number of farms reporting		%	Number of farms reporting		%
	2011	2006	Change	2011	2006	Change		2011	2006	Change	2011	2006	Change
1A	680	878	-22.6	269	552	-51.3	5A	1232	1685	-26.9	740	1263	-41.4
1B	557	794	-29.8	288	576	-50.0	5B	1166	1698	-31.3	793	1173	-32.4
2A	387	682	-43.3	141	323	-56.3	6A	1306	1660	-21.3	819	1244	-34.2
2B	602	997	-39.6	377	658	-42.7	6B	1074	1459	-26.4	521	899	-42.0
3AN	406	611	-33.6	129	267	-51.7	7A	730	1097	-33.5	308	607	-49.3
3AS	644	1016	-36.6	194	400	-51.5	7B	1022	1270	-19.5	403	690	-41.6
3BN	631	951	-33.6	325	642	-49.4	8A	918	1191	-22.9	532	724	-26.5
3BS	425	615	-30.9	218	403	-45.9	8B	1076	1488	-27.7	753	1076	-30.0
4A	267	325	-17.8	139	212	-34.4	9A	1285	1601	-19.7	812	1302	-37.6
4B	361	451	-20.0	121	209	-42.1	9B	865	986	-12.3	498	808	-38.4

Source: Statistics Canada Census of agriculture (2011 and 2006).

Grain is normally stored on farms after harvesting and then trucked to elevators. Producers decide whether to truck the grain themselves, use a for-hire trucking service to truck the grain or to utilize the services of commercial grain operators. Grain can be trucked to grain elevators or to a producer loading facility and occasionally, grain is trucked directly to domestic millers or to US markets. Grain is moved from grain companies by rail or by truck to either domestic users, US markets or to the port terminal. Grain is moved from the producer loading facility to the port via rail (Figure 2.8).

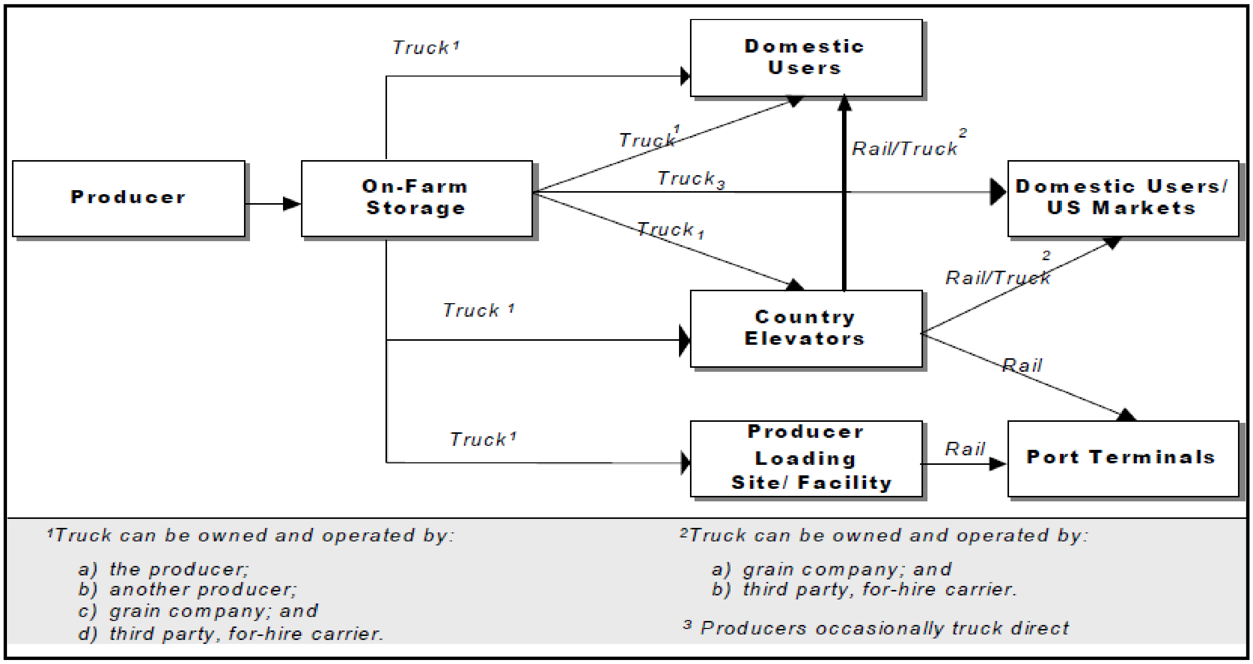

Figure 2.8: Trucking Within the Prairie Grain Handling and Transportation.
Source: Quorum Corporation (2002).

The Quorum Corporation (2002) noted that grain is commonly trucked to country elevators or less frequently, directly to rail hopper cars. It was further highlighted that the rationalization of railway networks and the subsequent decline in the number of elevators increased farmers' demand for commercial trucking. Prior to 1997, 95% of the grain delivered to elevators was delivered by farm trucks with a 5 to 10 tonne capacity with an average distance of 25 kilometers (Transport Canada, 2010a). With the closure of some elevators, farmers had to decide whether to haul their grain a greater distance or to sub-contract delivery to a trucking company. In an effort to gain the competitive edge over other elevators, some grain elevators partnered with trucking companies and offer both trucking services and grain handling services (Quorum Corporation, 2002). As a result, there has been a marked increase in the number of commercial short-hauls across the Canadian prairies. Figure 2.9 below shows a 32.2% increase in short-hauls in the 2009/10 crop year relative to the 1999/2000 crop year in the Prairies. This increase in trucking demand occurred in a context of a decline in the number of available country elevators (Doan, Paddock and Jan, 2003).

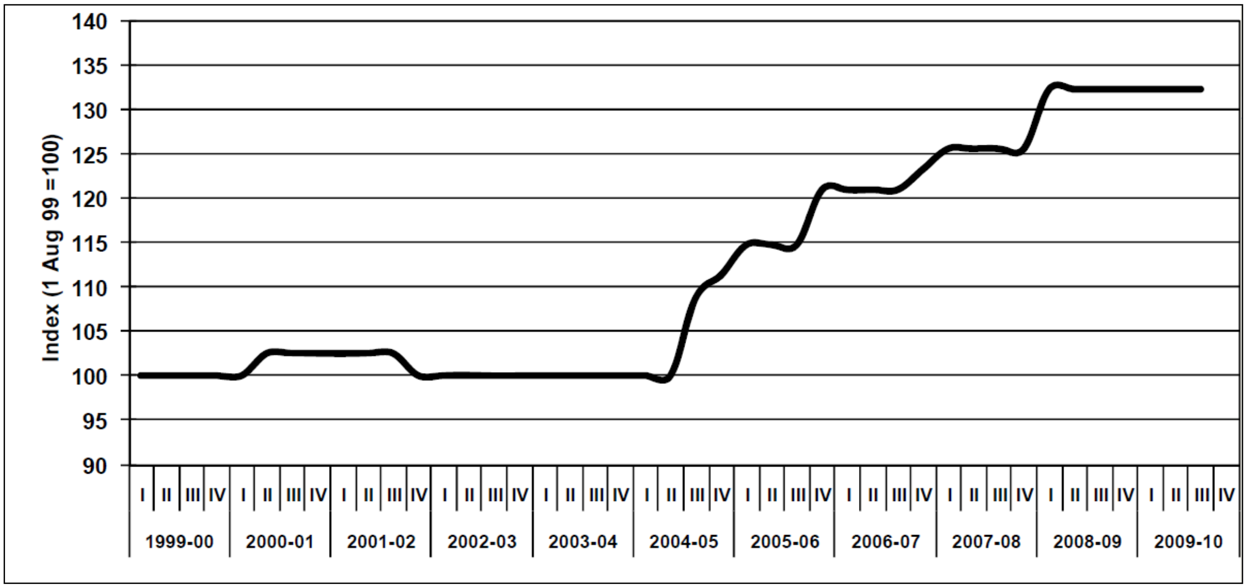

Figure 2.9: Composite Index – Short-Haul Trucking
Source: Quorum Corporation (2010)

The primary function of grain elevators is to receive, grade and prepare grain for shipment. They are responsible for calculating the dockage which is deducted from the farmer's payment. For these services grain elevators charge farmers a 'handling fee'. There are four types of elevators: primary, process, transfer and terminal elevators. Primary elevators receive grains for forwarding, storage or for both storage and forwarding, while process elevators receive grain for storage and value added processing such as milling into flour. Transfer elevators receive grain that has already been inspected and weighed at another elevator (some elevators in the east being an exception) and terminal elevators receive grain that has already been inspected weighed and cleaned and treats the grain before it moves forward in the supply chain (CGC, 2009).

Grain elevators are a located in many of the towns and cities on the Canadian prairies. However, there has been a decline in the number of grain elevators in operation and the significant increase in the level of firm integration over the past two decades. The decline in the number of elevators is attributed to the removal of the Crow Rate subsidy, which were payments made by the federal government to railway companies subsidizing the cost of grain movement to port (Storey, 2006), under the Western Grain Transportation Agreement Act of 1983. In 1995 farmers received a lump sum payment for the transition to an unsubsidized transportation system, which resulted in the abandonment of rail service to some towns and therefore made some elevators redundant

(Doan et al, 2003). Currently, there are approximately six major grain elevator companies in the Canadian prairies (Quorum Corporation, 2010), and as is shown in Table 2.5, there are 394 elevators in operation relative to 1,035 in 1999 (CGC, 2012).

Table 2.5: Number of Canadian Grain Elevators and Capacity

Year	Number of Elevators	Capacity in Tonnes
1999	1035	12,287,900
2000	909	12,709,370
2001	687	11,964,510
2002	484	11,254,860
2003	441	10,999,220
2004	421	10,975,910
2005	416	11,107,800
2006	402	11,125,600
2007	400	10,762,440
2008	401	10,869,110
2009	386	10,822,080
2010	394	11,118,080

Source: Constructed by author with data from CGC (2012)

Grain is mainly transported across western Canada via rail. There are two major railway companies that provide services to most of western Canada, Canadian Pacific Railway (CPR) and the newer Canadian National Railway (CNR). These two companies own approximately 36,300 miles of railway across North America (CPR, 2011; CNR, 2011). Like grain elevators, the national rail industry is characterized by oligopolistic (more specifically, duopolistic) behaviour and in an unregulated market they may be able to influence the price of rail transportation services.

Water is one of the cheapest modes to transport cargo (Min, 1991). Countries with developed waterways have found this to be a source of competitive advantage. For example, a well-developed network of waterways in the United States has led to increased intermodal competition which in turn has led to lower rail rates (Sorenson, 1973). The Canadian prairies, however, lack such a network. The closest ports are to the north-east (Port of Churchill), east (Thunder Bay) and west (Vancouver and Prince Rupert). Although Churchill is spatially the closest export position to a significant portion of the prairies, grain movement through this port is constrained to periods when the ice has melted in the northern water channels. Furthermore, crop movement to the western ports is complicated by the Rocky Mountain Range. To the east, the Great Lakes are the closest waterway. At the ports, crops are exported to international destinations using privately owned international vessels.

In 2010, there were, on average, approximately 29,000 workers employed in the Canadian marine transport industry and the value of commercial transportation was $985 million or 0.1 percent of GDP in 2010 (Transport Canada, 2010b). The importance of the industry is evident in its level of government involvelment even despite the consistent losses incurred by the St. Lawrence Seaway Management Company over the fiscal years 2000/01-2009/10 (Transport Canada, 2010b). Government operating, maintenance support as well as investment in port infrastructure totalled $225 million in 2010/11, while direct federal subsidies, grants and contributions from the Canadian government were $348 million (Transport Canada, 2010b).

On the international scale, the international ocean freight industry experienced robust growth for the period leading up to 2008, as the world became more integrated, trade expanded as countries removed domestic trade barriers (Sachs, Warner, Aslund and Fischer, 1995; Chase-Dunn, Kawano and Brewer, 2000; Baier and Bergstrand, 2007). As shown in Figure 2.10, world trade peaked in 2008 and was valued at US$16.9 trillion (WTO, 2012). The growth in trade is reflected in the increase in ocean freight rates. For example, nominal ocean freight rates increased from US$18.50 in the crop year 2003/04 to US$85.00 in the crop year 2007/08 per short tonne for shipments originating in the North Pacific destined for Japan (CGC, 2008; CGC, 2004).

Figure 2.10: The Annual Value of World Trade over the period 1991- 2011.
Source: Constructed by author with data from WTO (2012).

In the latter half of 2008, the shipping industry came to a standstill as international trade collapsed and freight rates plummeted. The accelerated growth in the ship building industry came to an abrupt halt in 2008 as the effect of the global financial crisis impacted the ocean freight industry. A semblance of normalcy returned to the markets in 2010 and 2011 as world trade recovered. Trade values grew from US$13 trillion in 2009 to US$18 trillion in 2011 (Figure 2.10).

This trend in trade is also depicted in ocean freights (Figure 2.11). There is an escalation in container freight rates beginning the second quarter of 2007, which peaked in 2008, then fell significantly toward the end of 2008 and the start of 2009, finally rebounding to some semblance of normalcy toward the end of 2009 (Slack and Gouvernal, 2011).

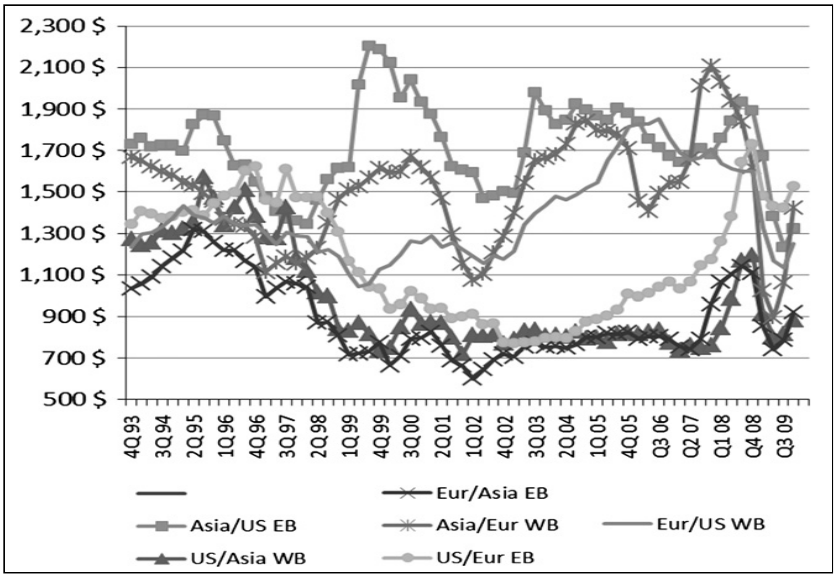

Figure 2.11: Container Freight Rates in Euros per Box
Source: Slack and Gouvernal (2011).

2.3.3.2 The Canadian Canola and Field Pea Supply Chains

Canola can be exported as seed or, processed domestically into oil and meal. The meal is used as a high protein animal feed while oils are used for food and biodiesel purposes (CCC, 2011c). The integral players in the food canola supply chain are the producers, grain facilities and canola crushing plants.

Despite the fact that there is a decline in the total number of farmers, the number of farmers in Saskatchewan who reported seeding canola increased by 5.3% to 15,736 in 2011 relative to 2006 (Statistics Canada, 2012). Geographically, the most significant increases are found in the southern part of the province. In particular the number of farmers who reported seeding canola in CAR 4b more than doubled between the two census periods (Table 2.6).

Table 2.6: Comparison of the Total Number of Farms that Reported Seeding Canola and Field Peas in 2005 and 2011

CAR	Canola (rapeseed)			Dry field peas			CAR	Canola (rapeseed)			Dry field peas		
	Number of farms reporting		%	Number of farms reporting		%		Number of farms reporting		%	Number of farms reporting		%
	2011	2006	Change	2011	2006	Change		2011	2006	Change	2011	2006	Change
1A	604	620	-2.6	115	248	-53.6	5A	1414	1401	0.9	187	370	-49.5
1B	583	569	2.5	64	162	-60.5	5B	1630	1668	-2.3	108	296	-63.5
2A	396	278	42.4	74	209	-64.6	6A	1465	1500	-2.3	407	664	-38.7
2B	827	527	56.9	316	579	-45.4	6B	1014	1003	1.1	365	481	-24.1
3AN	261	189	38.1	205	319	-35.7	7A	641	447	43.4	183	287	-36.2
3AS	341	180	89.4	389	598	-34.9	7B	933	908	2.8	454	445	2.0
3BN	417	290	43.8	471	683	-31.0	8A	1129	1239	-8.9	168	278	-39.6
3BS	104	74	40.5	232	398	-41.7	8B	1268	1487	-14.7	177	381	-53.5
4A	38	48	-20.8	87	159	-45.3	9A	1481	1474	0.5	374	447	-16.3
4B	165	76	117.1	238	241	-1.2	9B	1025	959	6.9	308	390	-21.0

Source: Statistics Canada Census of Agriculture 2011 and 2006.

Canola is trucked from the farmer to elevators and/or crushing plants. At the elevators, canola is cleaned and stored for shipment to port via rail. Most of the canola produced is exported to Japan. Canola that is trucked to crushing plants is cleaned, crushed and the oil is extracted and the residual meal is included in feed for livestock and poultry rations (Ainslie, Dowlatabadi, Ellis, Ries, Rouhany and Schreier, 2006). Canola oil is suitable for human consumption, as an input in other food products such as margarine or for a variety of inedible uses such as cosmetics and biodiesel (Figure 2.12). More than 85 per cent of Canadian canola is exported, with Japan and Mexico being the chief importer of the seed while United States is a significant importer of canola meal and oil (CCC, 2011d).

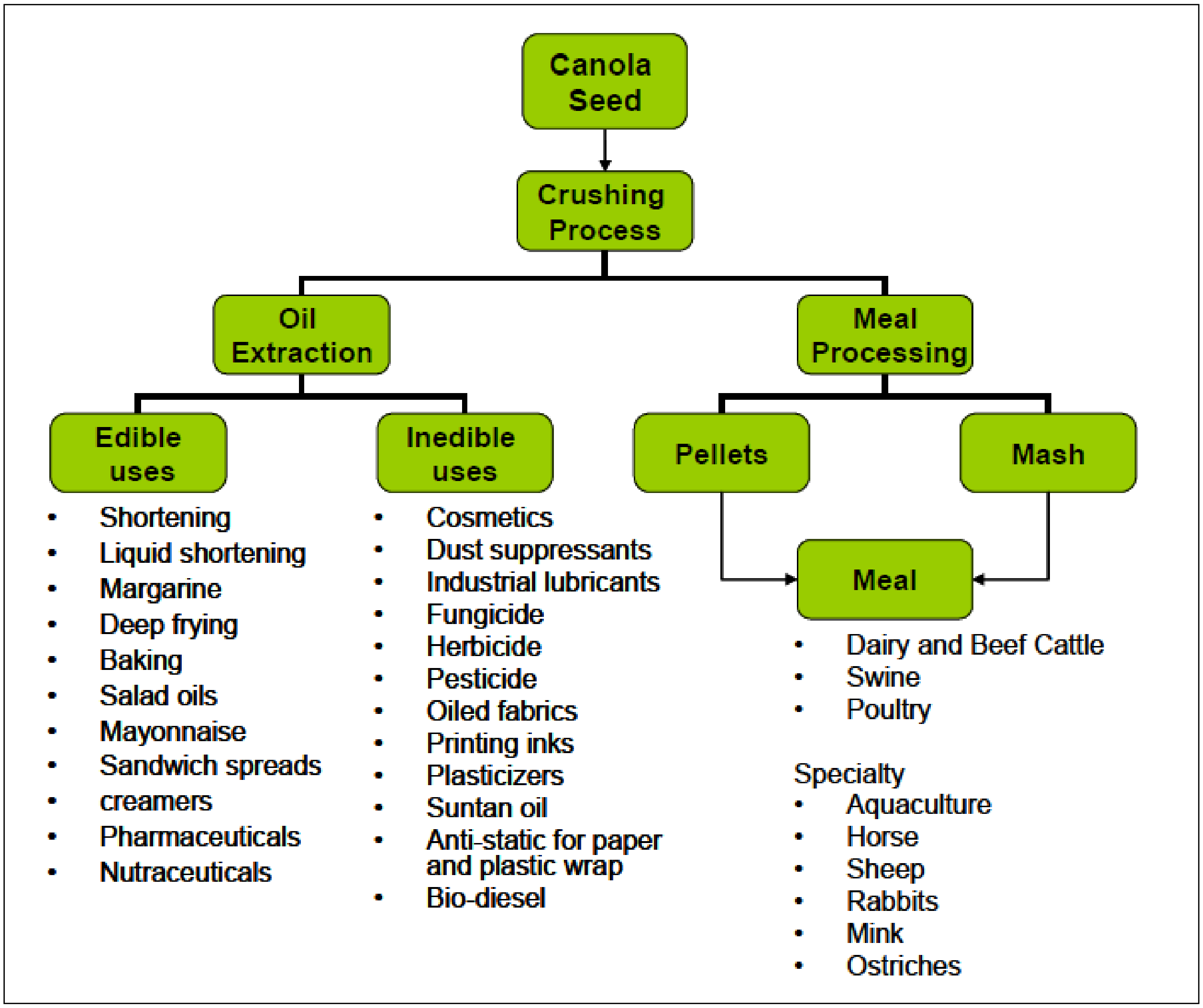

Figure 2.12: Canola seed to Oil Supply Chain.
Source: Ainslie *et al*., 2006.

The bulk field pea supply chain also begins with the farmer producing the crop. The number of farmers in Saskatchewan who reported seeding field peas decreased by 34% to 4,922 in 2010 relative to 2005 (Statistics Canada, 2012). More specifically, the number of farmers who reported seeding field peas in CARs 2a and 5a declined by more than 60% between the two Census periods (Table 2.6). Farmers then truck crops to a cleaning facility or to an elevator where it is cleaned and then it is transported via rail to the ports where it is loaded onto ships and ocean freighted to various export destinations.

2.3.4 Fuel Costs and Canadian Prairie Farming

Heichel (1976) highlighted that technology leads to increased productivity in agriculture that in turn is somewhat dependent on fossil fuels. Machinery such as trucks, direct-seeders and combines all make farming more efficient, but are driven by fossil fuels. This section shows that fuel costs are an important aspect of prairie farming and that these costs vary spatially across Saskatchewan.

Fuel costs in Saskatchewan farming was between 7.1% and 9.5% of total farm expenses in 2011 (Statistics Canada, 2012). This translates to a mean fuel cost per cultivated acre of $15.76. During the 2010/11 crop year, world crude oil prices rose to an average high of approximately $88.84 per barrel (NRCAN, 2012), which was approximately 66% of the cost in July 2008. Farm fuel costs differ spatially across Saskatchewan (Figure 2.13) where the spatial distribution of fuel costs per acre of cultivation in Saskatchewan is illustrated. With the exception of CAR 4b, fuel costs appear to increase as one moves in a northerly and easterly direction, hence indicating spatial heterogeneity in fuel costs in farming.

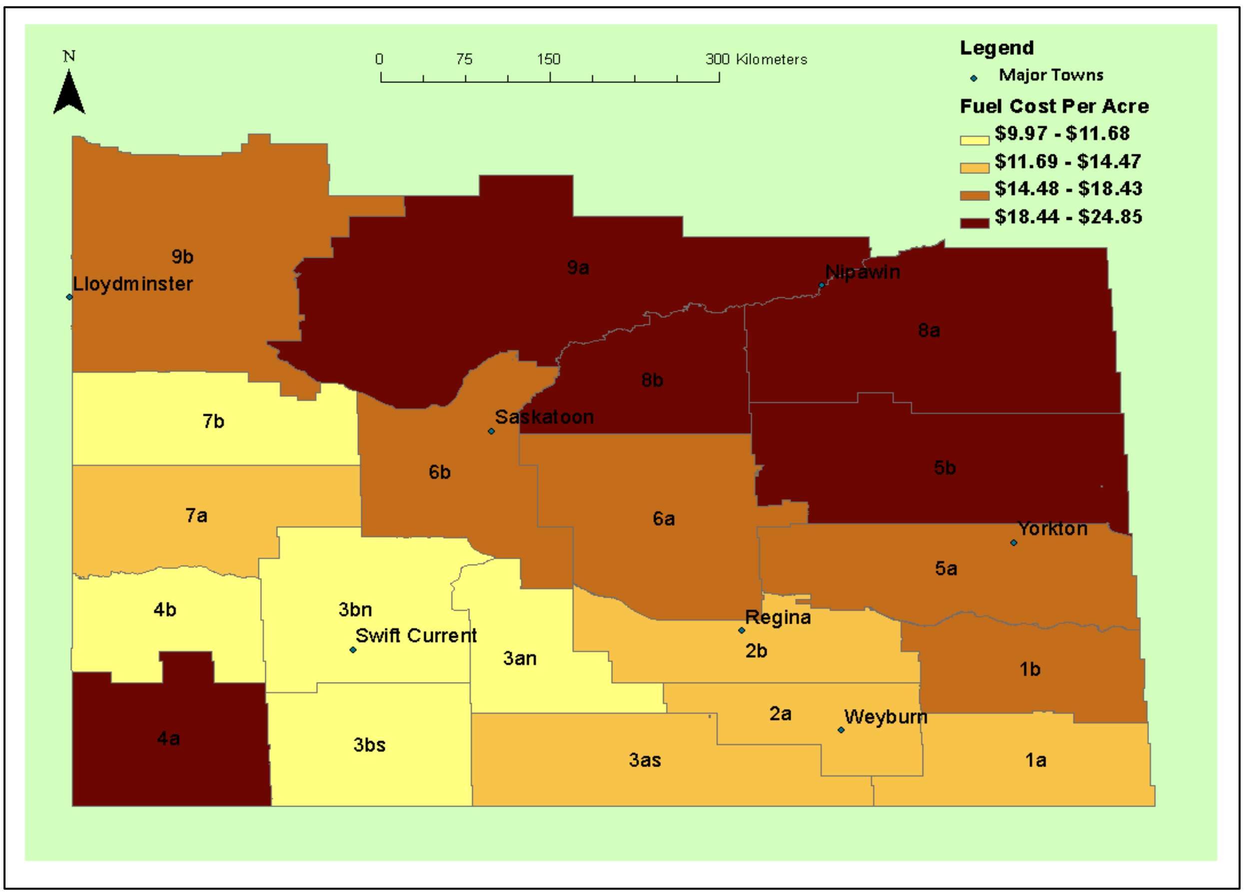

Figure 2.13: Composite Index –Spatial Distribution of the Fuel Cost Per Acre in Saskatchewan in 2010.

Source: Created by author with source data from Census of Agriculture Statistics Canada, 2012

Cost of production is both directly and indirectly influenced by oil prices. Figure 2.14 juxtaposes world crude oil prices with diammonium phosphate (DAP) fertilizer prices. During the 2008 oil spikes, there seemed to have been an increase in the correlation of the two prices. As confirmed by Baffes (2007), a 1% increase in oil prices is expected to translate to 0.33% increase in fertilizer prices.

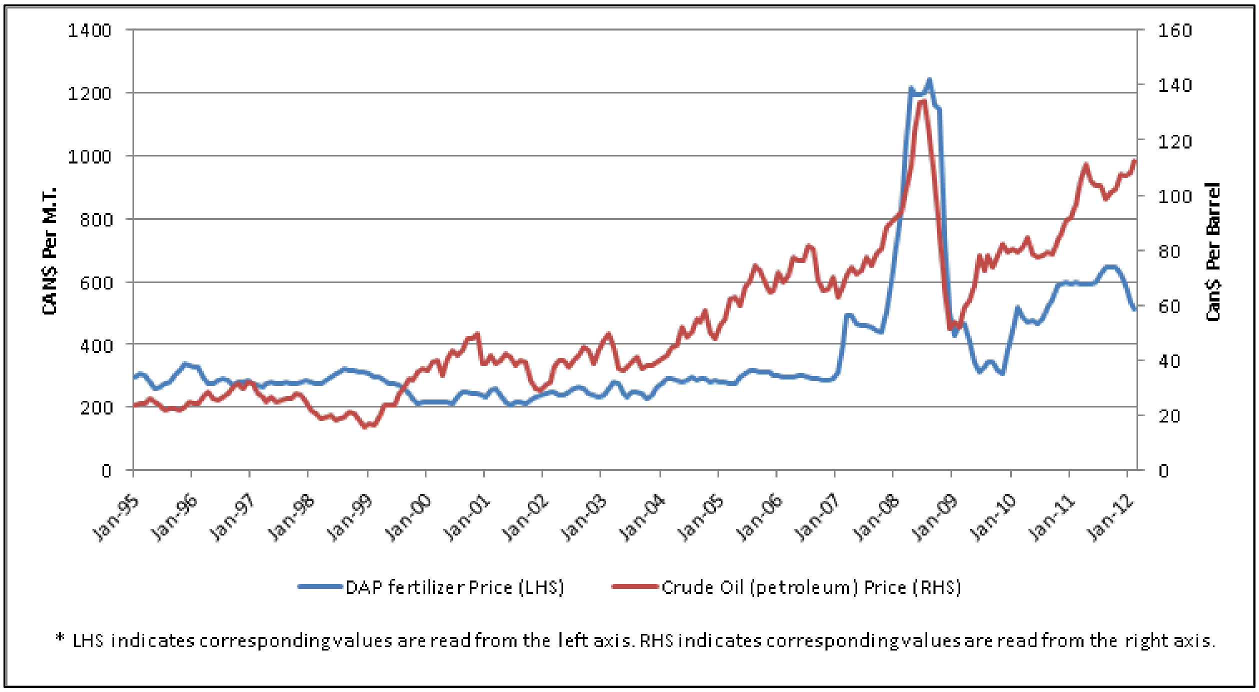

Figure 2.14: DAP Fertilizer Price and Crude Oil Price, 2005-2012
Source: Created by author with data from Index Mundi, 2012

2.3.5 Fuel Costs in Transportation

2.3.5.1 Fuel Costs and Trucking

Human Resource and Skills Development Canada (2012) noted that despite the increased demand for trucking services in Canada, the trucking industry's growth is still impeded by rising fuel costs. In a bid to recoup losses due to changes in the fuel cost, many of the larger carriers include a fuel surcharge with the additional cost being borne by the customer. Smaller, owner-operator trucking firms often cannot pass the surcharge on to the customer and must instead absorb these losses, resulting in smaller gross margins. As a result, some trucking firms have been forced to exit the market (HRSDC, 2012). Truck surcharge rates have been trending with fuel prices as is evident from Figure 2.15.

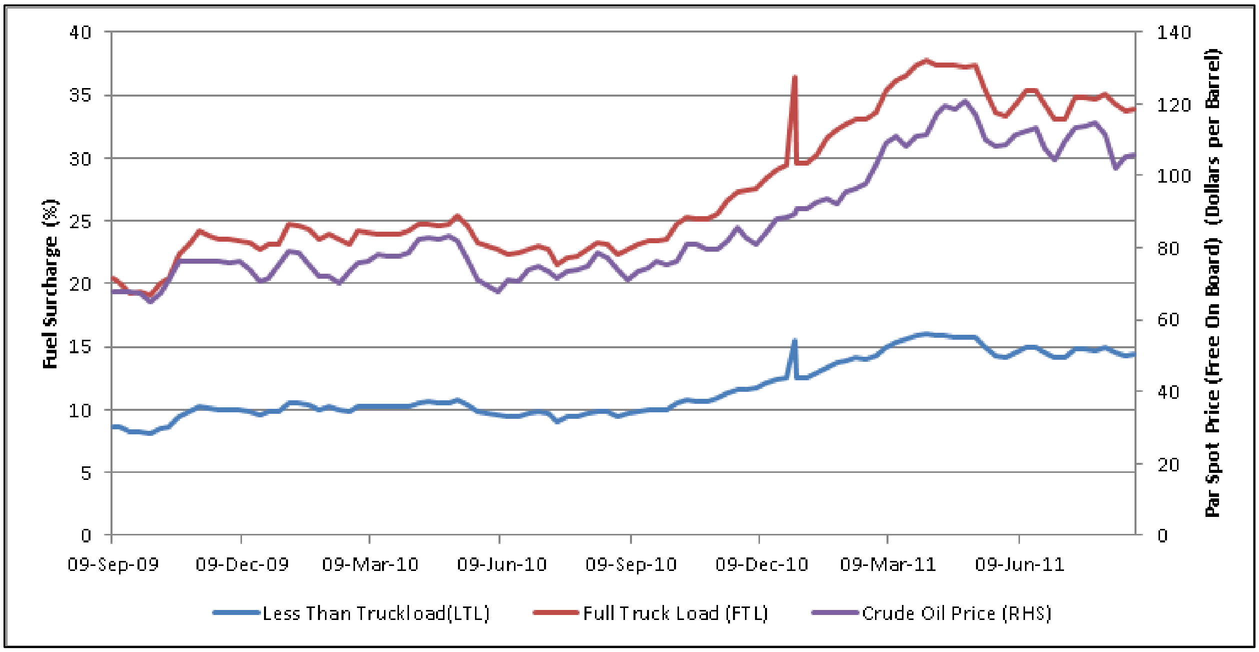

Figure 2.15: Trends in Canadian Domestic Fuel Surcharge and Oil Prices, 2009-2011
Source: Constructed by author with data from National Traffic Services 2012 and EIA 2011b

2.3.5.2 Fuel Costs and Rail

Canadian freight transport relies to a great extent on diesel fuel. As diesel fuel prices increase, the cost to the rail companies increase. The fuel cost per freight revenue[3] faced by the two major railway companies in western Canada is presented in Figure 2.16. It shows that between 1986 and 1997 fuel cost represented approximately 10% of freight revenues earned. The ensuing period was characterized by sustained and rapid increases in the ratio such that in 2008 the ratio was approximately doubled. It is also evident from Figure 2.16 that rail companies' costs generally trend with world oil prices, with peaks in 2008 and troughs in 2009 in all three time series.

[3] The ratio fuel cost per freight revenue is the total fuel cost divided by total freight revenues and shows how much is spent on fuel for every dollar earned in freight transportation.

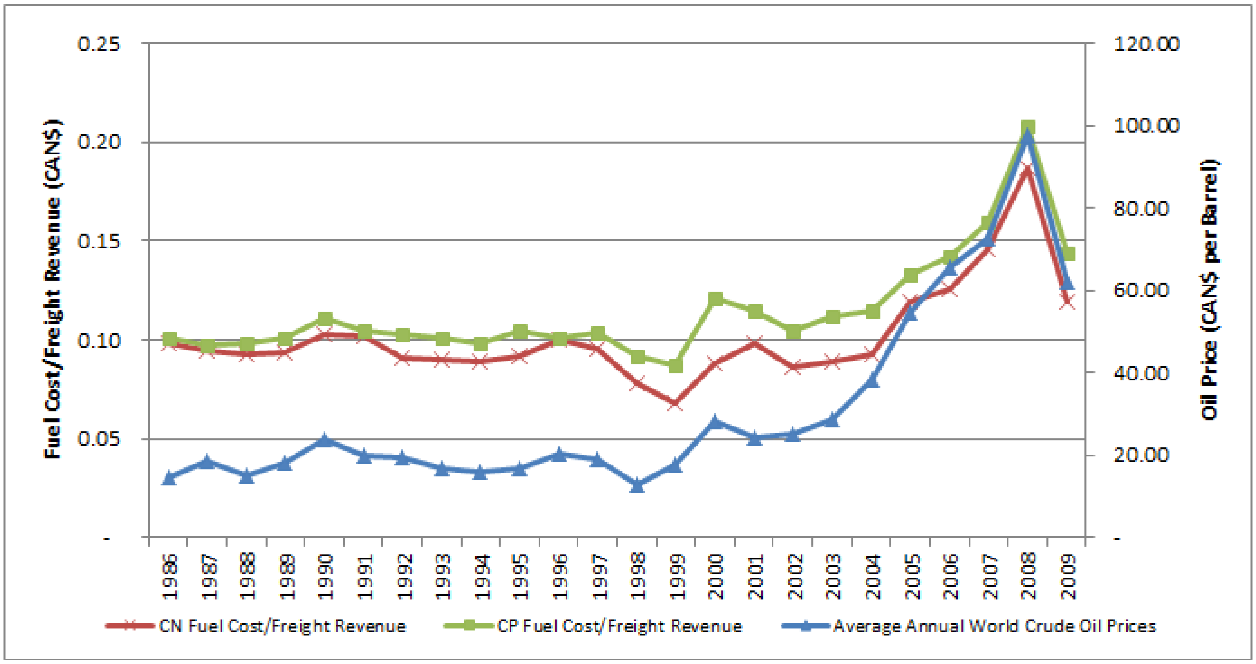

Figure 2.16: Canadian Fuel Cost Per Freight Revenue and Average Annual World Crude Oil Prices: 1986-2009
Source: Created by author with data from Statistics Canada, CANSIM Table 404-0012 and CANSIM Table 404-0004 and Index Mundi 2012.

2.3.5.3 Fuel Costs and Ocean Freight

With 80% of the world merchandise shipped by sea (UNCTAD, 2010), the shipping industry is vital not only to the Canadian economy but also to the world economy. The shipping industry is highly dependent on oil (UNCTAD, 2010). UNCTAD (2010) noted that a study by the Organisation for Economic Cooperation and Development (OECD) has also investigated the impact of oil prices on maritime transport costs. Various studies have calculated differing estimates of the degree to which ocean freight rates and oil prices are related. Depending on the specification, the OECD study estimated an elasticity of freight rates to changes in oil prices ranging from 0.018 to 0.15. Hummels (2007) confirms the relationship between ocean freight rates and oil prices but estimated that elasticities range from 0.232 to 0.327. Mirza and Zitouna (2009) estimated elasticity of freight rates to oil prices ranging from 0.088 to of 0.103. UNCTAD (2010) estimated that freight elasticities lie between 0.281 and 1.05. If the elasticities reported by UNCTAD (2010) are most accurate, then it means that crude oil price could significantly impact the cost of transporting bulk commodities such as grains from the Prairies.

With the variations in costs of production and distribution, changing world commodity prices and the unpredictability of weather patterns, the question is raised: how are these competing distribution chains able to maintain a consistent and stable supply? To answer this question the discussion turns to a review of the literature on supply chains and vertical coordination.

2.3.6 Vertical Coordination and Supply Chains

A vertical market structure is defined for a set of firms in which the membership for a firm is determined by the existence of a cooperative relationship with at least one other firm in that industry (Baligh and Richartz, 1967). The authors defined a cooperative relationship as one that facilitates the exchange of goods and services between firms within the industry. They further stated that inter-firm relationships are influenced by the nature of cooperation and competition that is found within that vertical marketing channel. Vertical coordination speaks to the nature of vertical cooperation that exists within an industry.

According to authors such as Williamson (1979), Henderson (1994) and Peterson, Wycowski, and Harsh (2001), the degree of vertical coordination can be placed on a continuum. At one end of the continuum, there are spot markets such as auctions which are used when no or minimal transaction costs are involved. However, as transaction costs increase, firms will move from spot markets towards contracts. The move towards vertical integration will continue as the likelihood of opportunism related to market uncertainty and asset specificity becomes more apparent with an increase in transaction costs.

Transaction costs can be separated into four different categories: search costs, negotiating costs, monitoring costs and enforcement costs (Hobbs, 2005). According to Hobbs (2005) search costs and negotiating costs are incurred *ex-ante* by entering into contracts and are associated with fees related to searching for and gathering information relevant to the industry and the negotiation of contractual agreements, respectively. On the other hand, monitoring and enforcing cost are incurred in *ex-post* contracting, and are associated with fees related to monitoring performance and legal fees that may be necessary to ensure the adherence to the terms of the contract.

Furthermore, increased vertical coordination may be beneficial for industries where supply uncertainty exists (Carlton, 1979). For example, increased vertical coordination could reduce the uncertainty involved in securing supplies and the cost that would have been incurred in re-negotiating one contract after another. Also, the likelihood of having to deal with opportunistic negotiators may also decrease as the terms of the contract are less likely to be abruptly or adversely altered. Furthermore, increasing the level vertical coordination provides producers a stable price throughout the contract period.

In examining the organic wheat supply chain in Canada, Ferguson (2004) sought to ascertain the most beneficial form of coordination for each participant in the distribution chain. He found that producers benefitted most when they vertically coordinated with a producer-owned-firm (POF). Marketers benefitted most when the marketing firm is large and purchases on the spot market. Ferguson also highlighted that if producers decided to deal directly with processors, bypassing the POF, the producers would be less efficient and less effective marketers. This result supports the model outcome of Balderston (1958) who stated that the introduction of a new level of middlemen would reduce transaction costs in the vertical structure and thus a market with significant transaction costs and no middlemen would find the entrance of a middleman cost efficient. Therefore, the level of coordination in an industry depends on the magnitude of transaction costs involved (Williamson, 1979; Frank and Henderson, 1992).

From the preceding discussion it can be inferred that any uncertainty in the wheat industry resulting from unpredictable oil price movements may result in increased vertical coordination to reduce transaction. There are other ways of cushioning the shocks from changing oil prices. This is manifested in Canada's initiative to reduce fossil fuel dependence and implement clean energy use.

2.4 Canadian Renewable Fuels Initiatives

The Canadian government invested $1.1 billion towards funding specific programs aimed at achieving the long-term objectives of reducing greenhouse gas (GHG) emissions under the

Kyoto Protocol (Government of Canada, 2000).[4] The Canadian federal government sought to reduce GHG emissions by promoting the blending of gasoline with ethanol to reduce GHG emissions in the transportation sector. This gave rise to the implementation of the Ethanol Expansion Programme (EEP).

As part of the broader Renewable Fuels Strategy, the EEP was created in August 2003 costing $234 million (Olfert and Weesen, 2007) in the hope of reducing GHG emissions, promoting biofuel production and encouraging the development and sale of renewable fuel technologies and to provide market opportunities for farmers in rural areas (NRCAN, 2010a). The EEP's specific objective was to provide economic support to firms constructing new ethanol plants or expanding existing capacity in an effort to develop more ethanol fuel markets and to increase consumer acceptance ethanol fuels (NRCAN, 2009).

In an effort to expand the ethanol industry, the federal government instituted renewable fuel blend mandates of 5% for ethanol (which took effect on December 15, 2010) and 2% for biodiesel (which took effect July 1, 2011) (CRFA, 2010a). The government of Saskatchewan increased the province's blend rate in from 5% to 7.5% in January 2007 (Enterprise Saskatchewan, 2012).

In addition to mandated levels of biofuel usage, the federal and provincial governments instituted incentives for ethanol producers to further promote development and sustainability of biofuel production (Pohit, Biswas and Jaya, 2009). The Saskatchewan provincial government passed the Fuel Tax Act 2000 that provided a 15¢/l tax exemption as a form of tax relief to biofuel producers (Fuel Tax Act, 2000; Pohit *et al*. 2009).[5] Pohit *et al.* highlight that the federal government had instituted a 10¢/l excise tax exemption on ethanol fuel but as of April 2008, the federal fuel tax exemptions were repealed and replaced with specific producer payments, called the ecoENERGY for biofuels program (NRCAN, 2010a). The amendment mandated that eligible firms could receive payments of up to 10¢/l for ethanol producing firms and up to 20¢/l for biodiesel plant (NRCAN, 2010b; Le Roy, Elobeid and Klein, 2009). Table 2.7 shows the

[4] In December 2011 the Canadian government withdrew from the Kyoto Protocol agreement (The Economist, 2011).
[5] The symbol¢/l means cents per liter.

schedule of incentive rates over the life of the ecoENERGY for biofuels program. Further restrictions apply under this program. Eligible firms should

- realize a return of less than 20% (Pohit *et al.*, 2009);
- produce at least 5 million litres of renewable alternative to gasoline or 3 million litres of renewable diesel (NRCAN, 2010c);
- not have received an operating incentive more than 30% of the 2 billion litre volume limit, and $500 million funding reserve for diesel producing firms (NRCAN, 2010c);
- have environmental assessments conducted by Natural Resources Canada (NRCAN, 2010c); and
- be constructed by September 2012 (NRCAN, 2010c).

Table 2.7: The Incentive Rate to Biofuel Producers over the Life of the ecoENERGY Program, 2008-2016

	Incentive Rate ($ per L)								
Fiscal Year*	**2008/09**	**2009/10**	**2010/11**	**2011/12**	**2012/13**	**2013/14**	**2014/15**	**2015/16**	**2016/17**
Renewable Alternatives to Gasoline	0.1	0.1	0.09	0.08	0.07	0.06	0.05	0.04	0.03
Renewable Alternatives to Diesel	0.26	0.24	0.2	0.18	0.14	0.1	0.08	0.06	0.04

* April 1 of a year to March 31 of the following year.

Source: Natural Resources Canada (2010b).

As a result of the support to the biofuel industry leading up to the 2008/09 fiscal year, the number of Canadian ethanol plants grew from 7 plants in February 2004 (Klein, Romain, Olar and Bergeron, 2004) to 14 operational plants in November 2010 (CRFA, 2010b). Capacity grew from 238 million litres per year in December 2003 to 1.67 billion litres in November 2010. There are 5 ethanol plants (Table 2.8) and 1 biodiesel plant (in Foam Lake) currently in operation in Saskatchewan with a combined plant capacity of 342 million litres per year for ethanol and 1 million litres per year for the biodiesel plant (CRFA, 2010). There is a proposed cellulosic ethanol plant with an intended capacity of 75 million litres per year to be constructed in Nipawin, Saskatchewan (Canadian Biomass, 2012).

Table 2.8: Locations and Capacities of Saskatchewan Ethanol Plants in 2010

Name of Ethanol Plant	Location	Capacity ('000's Litres Per Year)
Terra Grain	Belle Plaine	150,000
NorAmera BioEnergy	Weyburn	25,000
Husky Energy Inc.	Lloydminster	130,000
Northwest Terminal Ltd	Unity	25,000
Pound-Maker Agventures Ltd.	Lanigan	12,000
Total		342,000

Source: Created by author with information from CRFA (2010).

Biofuel production is capital intensive and there are a number of required processes to convert bioproducts to fuel. There are two broad classifications of biofuels: first generation and second generation biofuels. The following section discusses the first generation biofuel production process.

2.5 First Generation Ethanol Production and Biodiesel Production Processes

First generation biofuels refer to fuels created from grains, beans and oilseeds. The first-generation primary-process ethanol production commences with the purchase of the feedstock from farmers. In the United States the feed stock is predominantly corn (Morris and Hill, 2006; Persson, Garcia y Garcia, Paz, Jones, and Hoogenboom, 2009) but on the Canadian prairies and specifically in Saskatchewan, it is predominantly wheat (CRFA, 2010). Wheat with a low protein and high starch content such as the soft spring wheat and winter wheat varieties is preferred for ethanol production such as (FOBI, 2011).[6]

A six-step process is used in the production of ethanol from grain. Grain is first milled, cooked and then allowed to ferment. After the fermentation process is complete, the solution is distilled and separated into ethanol and co-products in the form of wet distiller's grain (WDG). The ethanol passes through dehydration and denaturing process after which it is ready for shipment to blenders who blend the ethanol with gasoline. Thereafter, ethanol blended gasoline is marketed to consumers. The co-products can be used as high protein component of feed for livestock. Figure 2.17 illustrates the process of ethanol production of an integrated ethanol plant and livestock feedlot on the Canadian prairies.

[6] On the other hand, food wheat attracts the highest price when it has a high protein and low starch content. Sometimes when hard wheat varieties fail to meet the high protein requirements for food it is redirected, ex post, to biofuel production. This ex post decision creates added complexity to a complex model and is not explored in this thesis.

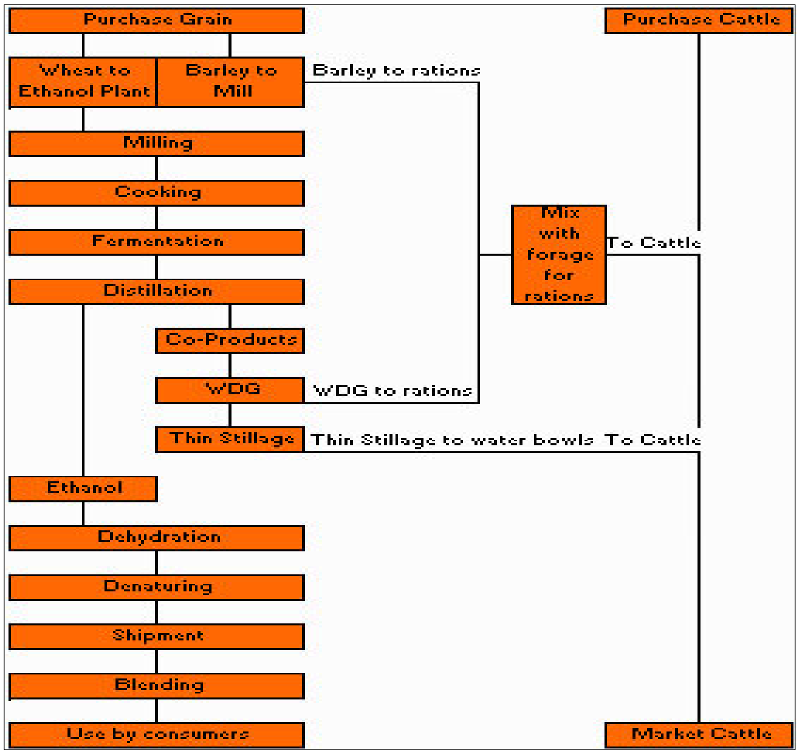

Figure 2.17: Production Processes of an Integrated Ethanol Plant and Livestock Feedlot in Saskatchewan
Source: Pound-Maker, 2005.

Biodiesel is made from vegetable oil, oilseed oil and/or animal fat through a process called transesterification (NREL, 2009). Transesterification is the process by which glycerine is separated from feedstock oil by adding methanol and potassium hydroxide. The glycerine produced can be further refined and be reused in the biodiesel production process or can be used in cosmetics and soaps. The co-product of the transesterification process is crude biodiesel which through further refining can be blended and used in diesel engines or it can be reused in the biodiesel production process. The stages of the biodiesel production process are shown in Figure 2.18.

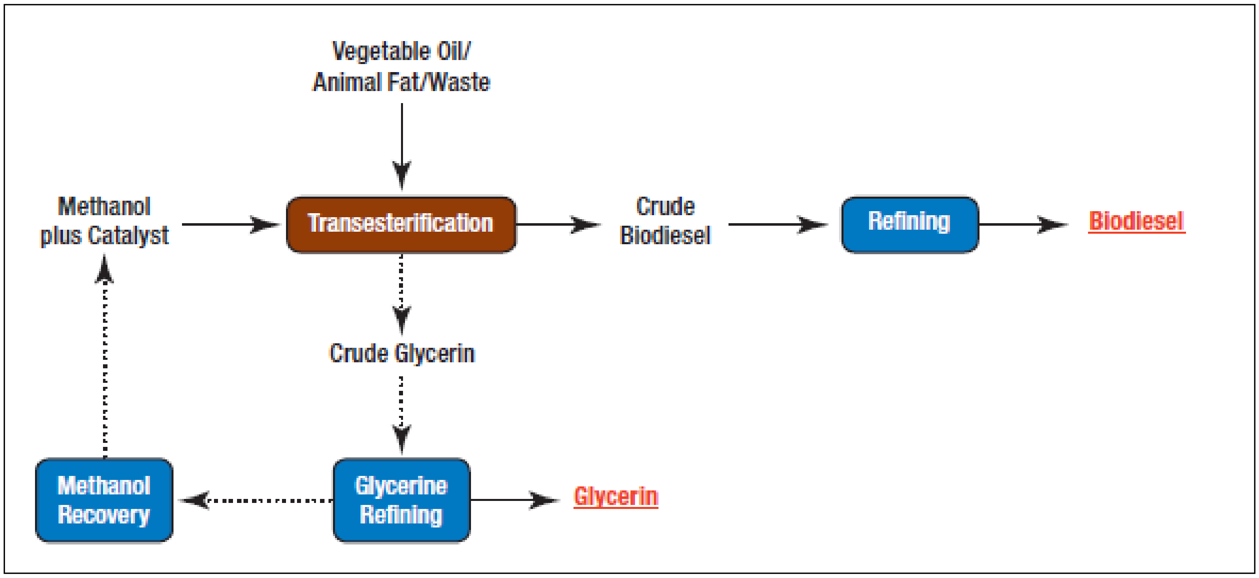

Figure 2.18: Stages in the Production Process of Biodiesel.
Source: NREL, 2009

2.6 Farmer Land Use Decision Models

The discussion now turns to topic of modelling. A model is a simplified construct of reality (Miller and Page, 2007). The primary aim of a model is to give insight as to the likely outcomes based on a set of assumptions and changes in model variables (Miller and Page, 2007). In this section an overview of some of the various models used to examine changes in land use is presented.

2.6.1 A Brief History of Land Use Modelling

Models of land use have been in existence for almost two centuries (De La Barra, 1989). Most models are concerned with either land use of farmers and how it impacts land values or land use decisions regarding urban planning and development (Wingo, 1961; Alonso, 1964; Parker, Manson, Janssen, Hoffmann, Deadman, 2003). More recent applications explore the impacts that varying of land uses has on the environment (Seecharan, Gill, Kulshreshtha, Junkins and Bussler, 2002; Happe, Hutchings, Dalgaard and Kellerman, 2011) and some others explore the suitability and profitability of energy crops (Scheffran, BenDor, Wang and Hannon, 2007; Scheffran and BenDor, 2009; Acheampong, Dicks and Adam, 2011; Song, Zhao and Swinton, 2011).

Von Thünen in 1817 (and later his work translated into English in 1966) was first to propose a model that explained the effects of transport costs on the location of activities and the functioning of the land market (Von Thunen 1966; De La Barra, 1989). Von Thünen's model assumes a large number of producers and landowners so that no individual producer or land owner is able to influence market price. It also assumes that land owners rent to the highest bidding producer; land is homogenous; a closed model; where there is no interaction with other regions; only one market centre where producers sell their crops and there is no cost to entry or exit. This model shows that the price of the agricultural commodity influences the willingness (ability) of a producer to pay a land-owner rent for the land (Von Thünen rent) (De La Barra, 1989). Thus land that is closest to the market (which is in the centre of the system) would attract the highest value and farmers planting the highest valued crop would be located closer to the market centre (De La Barra, 1989). The model also demonstrates that as crop competition increases, land values increase. Since land is a factor in the production of crop, crop prices also increase, which in turn leads to reduced demand for crops. As the quantity demanded decreases, producers are forced to find novel techniques to increase demand (De La Barra, 1989).

Wingo (1961) and Alonso (1964) expanded the work of Von Thünen (as found in De La Barra, 1989) by adding budget constraints adapted to an urban phenomenon analysis. However, De La Barra notes that these models are limited in that they have only a few feasible solutions that are difficult to realistically observe. He further noted that relaxing the assumption of one market place (Von Thünen) and the center of employment (Wingo and Alonso) causes the model to collapse. Another limitation noted by De La Barra (1989) is that the theoretical models suggest that individual demand curves can be summed to form an aggregate demand curve but he points out that demand curves could in fact vary by location and thus aggregation could lead to generalized inaccuracies. De La Barra also states that these limitations could be overcome by the use of spatial interaction models.

Spatial interaction models were first made prominent in the work of Hansen (1959). The work of Wilson (1970) expanded the concepts of Hansen by introducing the maximum entropy approach in modelling. Wilson (1970) provided the platform for modelling a more general theoretic framework (De La Barra, 1989).

In Canada, the Canadian Regional Agricultural Model (CRAM) is a sector equilibrium model that is disaggregated across cereals, oilseeds, forage, potatoes, meats and animal by-products (eggs and dairy) over 55 agricultural regions in Canada (Gill and Colwill, n.d.). Production levels are converted from linear functions to non-linear functions using positive mathematical programming and optimized in General Algebraic Modeling System (GAMS) for each commodity in each region. The results that are yielded are static, spatially computed partial equilibrium results. The model has been used for various policy analyses in the areas of production (Webber, 1986), transportation (MacGregor Jenkins and Barber, 1994) and environmental impacts and assessment (Seecharan *et al.*, 2002). Most recently Colwill (2006) and Smith (2009) have modelled biofuel production analyses. Smith (2009) uses CRAM to assess the impact of increased ethanol targets on the crop income, livestock and land use cover. He finds that increased ethanol targets have a significant impact on crop income in Alberta, Manitoba, Ontario, Quebec and Saskatchewan. He further notes that the impact to the livestock sector is minimal but that the impact on land cover is significant. Just below 300,000 acres of shrub land would be incorporated into agricultural production in Alberta, just over 150,000 acres of both shrub and forest land would be converted to agriculture in Ontario and approximately 75,000 acres of shrub land would be converted in Saskatchewan.

More novel approaches have been used to determine land use in agriculture, especially in light of the impetus towards the development of renewable fuels, include Song *et al.* (2011) who used a real options methodology to analyze farmers' land use decisions as it pertains to the switching between traditional crops to energy crops. One of the significant contributions of using the real options approach is the fact that farmers cannot only switch from traditional crop rotations to energy crops but they can also switch back to traditional crops from energy crops, albeit at a cost. The authors concluded that for farmers converting to energy crops, the returns from energy crops would have to be more than double current returns before farmers begin switching. This is due primarily to the significant costs associated with switching.

Acheampong *et al.* (2011) assess the impact of energy crop production for the use of biofuel purposes on US hay markets. The authors utilize ordinary least squares (OLS) to estimate and predict hay prices in Oklahoma. These prices were in turn used to parameterize a linear programming (LP) model that examined the profitability of the production of hay in excess of the profitability of energy crops. Their LP results showed that land set aside for energy crop production is likely to replace land used for hay thereby adversely affecting grazing animal production.

Feng and Babcock (2010) used a theoretical approach to ascertain the impact of increased productivity yield on land use decisions under two regimes, government subsidies to ethanol producers and mandates of ethanol consumption. The land use options available to farmers were to either continue development of cultivated land (corn production) or to transform uncultivated land (forest or grassland) to agricultural purposes. They found that in the scenario of increasing yields and government subsidies to the ethanol industry there would be an expansion of cultivated acreage, thereby transforming uncultivated land to farmland. The authors argued that this occurs as the return to cultivated land would be higher than that of the uncultivated land, thus making it more profitable to transform uncultivated land. Conversely, they found that increasing yields under a government mandate would translate to decreasing cultivated acreage, as less land would be required to meet the existing demand.

These models provide valuable insights into modelling land use. However, these models in one way or another, lack the ability to explain emergent phenomenon, to take into account factors such as spatial relationships, agent heterogeneity or complex agent interactions. Agent based models can take these factors into account.

2.7 Agent Based Models

Agent based models (ABM) are able to represent economic, dynamic social and environmental complexities by simulating interactions and feedbacks between agents with other agents and agents with the environment over time (Parker *et al.*, 2003). This section reviews some of the literature on agent based modelling. This section also seeks to highlight the benefits of this modelling approach as a justification of the land use modelling technique chosen for this thesis.

2.7.1 European ABM Studies

Several studies have applied the agent based approach to modelling. Balmann (1997) utilized ABMs in the analysis of path dependences of structural change in agriculture. Path dependence is defined by Page (2006) as the notion that current and future states, actions or decisions depend on, or are influenced by previous states, actions, or decisions. Balmann developed AgriPoliS, a cellular automaton model (CM), which divided the landscape in ordered plots over which farms compete. The model is based on a number of individually acting farms located at different points in an agricultural region. Farms utilize a two-crop rotation and optimize their activities with respect to their expectations, financial state and existing assets. The author assessed model outcomes under varying initial conditions in the size of the modelled region and the varying levels of spatial density of farms on the landscape. He concluded that structural change is indeed path dependent.

Happe *et al.* (2011), Happe, Balmann, Kellermann and Sachrbacher (2008), Happe (2006), also used AgriPoliS to ascertain the impact of various policy schemes on agriculture in Germany and Denmark. In Happe *et al.* (2008), the authors found similar results to that of Balmann (1997), in that the impact of policy changes on structural change in agriculture depended on the initial structure. Happe *et al.* (2011) combined AgriPoliS with the N-FARM model to assess the impact of structural change in agriculture on environmental emissions in Denmark. The authors found that structural change does impact the surplus accumulation of environmental gasses.

ABMs provide increased research flexibility in that they can model complex relationships that otherwise would be impossible to capture. One such behaviour is that of imitation. Polhill, Gotts and Law (2001) conducted a simulation-based study of agent imitation in decision making within a spatial framework over time. It compared the use of imitative relative to non-imitative land use practices and was concerned with improving the understanding of land use change in rural Scotland. The authors developed the FEARLUS simulation model for their study. The model indicated that the spatial and temporal structure of the environment and the strategies of other agents are important in defining the relative competitive properties of different strategies. The authors note that the success of a range of imitative strategies depends on the context in which imitation is taking place.

2.7.2 North American ABM Studies

Some of the prior ABM graduate thesis studies at the University of Saskatchewan are closely related to the studies authored by Balmann and Happe. The works of Freeman (2005), Stolnuik (2008) and Anderson (2012) have all sought to assess the effects of structural change on Canadian prairie agriculture using ABMs and endogenous land markets. Freeman modelled the dynamic relationship between farm households and the resulting impact on the agrarian structure of a proto-typical rural municipality in the dark-brown soil zone region of Saskatchewan. Freeman also investigated the impact on land values. The ABM framework allowed for analysis of the impact of farmer management style on structural change. The thesis found that the incorporation of varied management styles marginally improved the survival rate of farm households.

Stolnuik (2008) expanded the model of Freeman to capture the effect of mixed farms, economies of size and lumpiness of machinery investments on Saskatchewan agricultural structure. The author found that farms willing to produce livestock had an increased likelihood of survival as they were able to exploit returns from marginal land. His thesis also concluded that lumpy machinery investments engendered economies of size. The investment in machinery increased profits, which in turn, increased land bid values. Higher land bid values made it harder for small farms to grow and compete.

Lawrence (2011) assessed whether instituting an open access policy in the rail industry can curtail the behaviour of incumbent rail companies and to compute the effect of delayed grain shipment across the Canadian prairies to export position. He found that open rail access may lead to improved rail service. He however noted that the increased competition could in fact lead to both increased services and increased cost of shipping.

Anderson (2012) built on the works of both Freeman and Stolnuik. Anderson identified the economic conditions that would prompt farmers to grow second-generation biofuel (SGB) crops. He also assessed the impact of SGB cropping on beef cow production and cropland use. The author found that energy crops have the potential to impact agricultural industry structure when biofuel prices are in excess of $2 per gigajoule. He further notes that beef cow farmers are better off with the introduction of energy crops while grain farmers are negatively impacted as there is less land available which hampers their farm growth, their ability to compete and ultimately their likelihood of farm survival.

Scheffran *et al.* (2007) and Scheffran and Ben Dor (2009) assessed the environmentally responsible and economically efficient agricultural land use options for the widespread implementation of renewable bioenergy crops. Their research identifies current and future obstacles and opportunities for renewable energy resources in Illinois, USA. They utilize an agent based model of system dynamics incorporating spatial elements using geographic information systems (GIS) to determine the incorporation of energy crops into the cropping mix of farmers. They take into consideration such factors as crop demand, price, subsidies and carbon credits as well as the location of ethanol plants and transportation patterns. They find that with increasing demand for biofuels, farmers will adjust their priorities to perennial biofuels mainly in the southern part of the state.

Parker and Meretsky (2004) present an agent based model of land use that examines two competing land uses and the impact of their spillover effects. It is designed to test microeconomic theories of land use such as those posited Von Thünen (Polhill et al., 2008). Polhill *et al.* likened Parker and Meretsky's model to an agent based equivalent of the cobweb model found in Ezekiel (1938), where, as shown in Figure 2.17, price expectations influence land-use decisions, which in turn determine the supply function. The supply interacts with the exogenous demand and reveals the realized price.

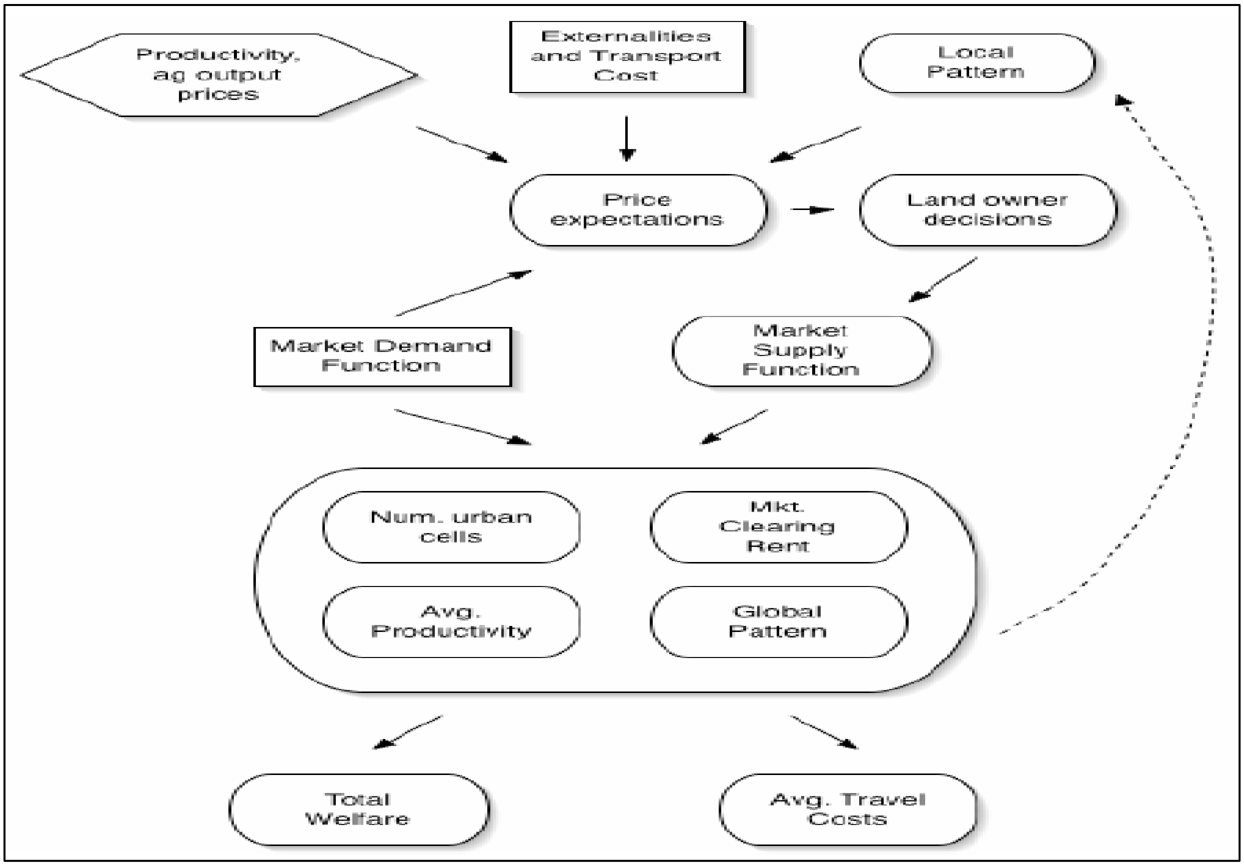

Figure 2.19: SLUDGE Process Overview
(Ovals are endogenous/emergent elements; lateral boxes are exogenous/initialisation elements)
Source: Polhill *et al.* 2008

In the model used by Parker and Meretsky (2004), there are two potential uses for land, agriculture or urban development. The landscape is subdivided into parcels and the profitability of land use at each individual parcel is computed. Profit for agriculture is given by the agricultural revenue less the fixed cost of the externality generated by urban activity. The profit for urban land is computed by urban revenue less the negative externality of neighbouring agriculture land, less the negative externality of neighbouring urban patches and less the fixed transportation cost based on the Euclidean distance from the market located at the city center influences. The negative spatial externalities in the profitability function create edge effects.[7] Parker and Meretsky also note that when transportation costs and the strength of demand for urban land influence landowner decisions, the model produces the classic Von Thünen outcome. That is, parcels with the highest profit are the one closest to the center market. Put another way,

[7] The edge effects are referred to as “edge-effect externalities” (Parker, 2000).

land attracting the highest rents is spatially closer to the center market and appeared in concentric proximity to the center. With the inclusion of urban setback, agriculture-urban externalities and not-in-my-backyard (NIMBY) effects and after increasing transportation costs, the spatial pattern outcomes move further away from the Von Thünen outcome.

2.7.3 Advantages of Agent based Model Land Use Modelling

Parker *et al.* (2003) review the emerging modelling technique of agent based (ABM) or multi-agent simulation models (MAS). They observe that MAS (also known as land use cover change (LUCC) models) are models that combine two key components, the cellular model and the agent based decision-making model into an integrated system. The authors highlight that models can be classified as equation based, system models, statistical techniques, expert models evolutionary models, cellular model, hybrid models and agent based models. Table 2.9 provides a summary of the advantages and disadvantages of some of these approaches.

Table 2.9: Pros and Cons of Equation Based, System and Statistical Techniques Models

Model	Advantages	Disadvantages
Equation based	Allows for quantification of theoretical models	Must obtain numerical or analytical solution which limits the complexity of the model
System models	It allows for inter-temporal analysis which allows feedback over time	Requires explicit identification of functional relationships over time and it is difficult to capture spatial relationships and is done at a very aggregated level
Statistical techniques	Use of econometric tools allow for the modeling of spatial relationships	De-emphasizes the importance of decision making and the effect of institutions. Parameters represent average effects only useful for explaining dynamics of stationary processes and uniform over space and time.

Source: Constructed by author with information from Parker *et al.* (2003).

Agent based models may be preferred to other models when one wants to capture the impact of autonomous, heterogeneous, goal-oriented decision-makers, which take into account, the environment in which they make their decisions (Parker *et al.*, 2003). Parker *et al.* highlight that ABMs can be used to model complex dynamic systems and that ABMs are also able to spatially represent interactions and feedbacks between socioeconomic and biophysical environment over time. This in turn, can reveal emergent phenomena resulting from decisions made by autonomous, heterogeneous agents.[8]

Another feature of ABMs is the modelling of adaptation (Polhill *et al.,* 2008). Parker *et al.* (2003) note that adaptive systems can influence outcomes at both the micro and macro scales. Agents adapt as they interact with other agent or the landscape and alter their behaviour in many diverse ways that can be hidden by the overall system behaviour (Smith and Page, 2007).

The ability to model dynamics is a significant advantage of ABMs. Smith and Page (2007) note that non-ABM modelling approaches may be suitable when transition paths are short and conditions are stable. Parker *et al.* (2003) corroborate this and further note that, in reality, parameters may not be stable over time and further indicated that when spatial heterogeneity influences model outcomes ABMs models are suitable.

This thesis seeks an approach that can model the complexities of four competing crop supply chains. The model must consider the spatial implications of distribution and transport costs. The selected model should be able to model interactions between agents and the landscape (in terms of productivity and cost) and agents and other agents in the model. Also, the model should be able to reflect the adaptive behaviour of elevators to changes in the model environment and reflect any emergent pattern from the industry. It is for these highlighted reasons that this thesis employs an agent based approach.

[8] Auyang (1998) defined emergent phenomena as “the higher level structures that are both qualitatively and quantitatively different from their lower level components and not obtainable through aggregating, averaging, or other superposition of the micro-level components” (Parker *et al.*, 2003, p. 323).

CHAPTER 3: *FARMCHAIN*: AN AGENT BASED MODEL OF FARM COMMODITY SUPPLY CHAINS

3.1 Introduction

The previous chapter highlighted some of the benefits of agent based modelling. This chapter puts forward the agent based model utilized in this thesis. This ABM, labelled the '*FARMCHAIN*' model, is characterized by competing crop supply chains that originate at the farm level. The *FARMCHAIN* model allows for the analysis of changes in farmer land allocation and its impact on elevator behaviour within the supply chain.

While there may be some inherent similarities found in the model used in this research and Anderson's (2012) modelling biofuel adoption and Lawrence's (2011) modelling of crop movement to export port position, this model is structurally different in its focus. That is, the *FARMCHAIN* model seeks to capture the macro-scale emergent phenomena of elevator pricing behaviour from increased crop competition and higher energy costs.

Very little is known about wheat pricing behaviour under the post single-desk selling era of Canadian grain elevators as, under the single-desk selling regime elevators had little control on the impact on farmgate prices as the industry was highly regulated (Schmitz and Furtan, 2000). However with the passing of the *Freedom of the Farmer Act* (Bill C-18, 2011), elevators may more strategically price their own services, influencing net farmgate prices, and potentially inducing more uncertainty as to the ramifications of their future behaviour. Crop production in western Canada is characterized by many heterogeneous farmers located on a productively variable landscape. In addition, western Canadian farmers produce a variety of crops whose mix has been shifting over time, resulting in multiple competing supply chains which include wheat and other cereals export for food, cereals for ethanol and canola for crushing plants or export. The ability to explore elevator behavior in a spatially competitive and dynamic context with many heterogeneous agents is one of the major advantages of agent based modelling. That is agent based modelling allows for the simulation of future elevator behaviour under structural change, new business conditions or a changing climatic environment. The next section describes the structure and flow of the *FARMCHAIN* model, commencing with an overview and thereafter describing the model in greater detail.

3.2 An Agent based Model of Supply Chains-The *FARMCHAIN* Model

The approach utilized in the *FARMCHAIN* model is a variant of the Simulated Land Use Edge Effects (SLUDGE) model proposed by Parker and Meretsky (2004) in that it follows the classical cobweb model in agricultural economics (Polhill *et al.*, 2008), but in this case, crop supply is only influenced by prices of the previous period and expected future prices.

3.2.1 Model Overview

This section provides an overview of each agent in the model and how they relate to each other. The *FARMCHAIN* model includes five types of agents: 1) farmers; 2) grain elevators; 3) canola crushing plants 4) ethanol plants; and 5) a biodiesel plant.

Farmers have two primary roles *FARMCHAIN* model: 1) farmers decide cropping mix and land allocations and 2) farmers make trucking or distribution decisions. Famers initially observe world prices and allocate their land to four crops: wheat, canola (CAN), barley (BAR) and field peas (FP), this is the rotation problem. While the rotation problem can be solved using linear programming problem (further discussed later), the computational time increases significantly due to the large number of farmer agents. Within the rotation problem is the sub-problem of which wheat type to grow: wheat types: wheat for biofuel (FW) and spring wheat or wheat for food (SW).[9] It is assumed that the wheat types are perfect substitutes.

Farmers decide which of the the soft or the hard wheat varieties to be planted based on their relative expected gross margins. After the farmer solves the sub-problem, the farmer decides how much land should be allocated to wheat and the other three crops based on the expected returns of the four crops. Crop land allocation after the first period is based on the expected gross margins. Expected gross margins are a function of the preceding period's prices, current prices,

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[9] As highlighted in Section 2.5, preferred wheat for food is generally high in protein and low in starch while wheat for biofuel production is ideally low protein and high starch.

production costs, storage and handling, trucking, rail and ocean freight costs. After harvest and depending on the crop, farmer agents select the destination and market. They can haul the crop to an elevator, a crushing plant and/or an ethanol plant. Biofuel wheat is trucked directly to the ethanol plant, while food wheat, peas and barley are trucked to elevators. Farmer agents can truck canola to either an elevator or a crushing plant, whichever is closer. After farmer agents identify and haul the crop to its destination, actual trucking costs and applicable elevator costs are calculated.

In the case of deliveries made to an elevator, elevator agents compute fees for handling and storage based on the level of spatial competition that exists within a predefined proximity radius. As time progresses, elevators adjust handling and storage fees based on the amount of crop received relative to the other competitors within their proximity radius. Elevators allocate crops received to either export or domestic use. In the case of export crops, rail transport costs to the ports are then computed and apportioned to the farmer based on relative quantities sent to the elevator. Crops directed to port are then assessed for ocean freight costs and apportioned to the farmer based on relative quantities produced.

Domestically processed crops include canola crushed for food/feed export (oil and meal) and biodiesel; and wheat for biofuels. Canola production is assumed to be directly hauled by truck to one of six oilseed crushing plants or to a grain elevator, whichever is closer. Oilseed crushing plants are assumed to charge the average storage and handling fees charged by other elevators plus an additional crushing margin. It is assumed that a portion of the crushing plant’s product is transported to export position by rail with the remainder being transported to the biodiesel plant by rail. Actual allocations are based on historical patterns. Thereafter, actual associated rail costs computed and apportioned to the farmer.

Ethanol and biodiesel plants produce biofuels. Biofuels produced first satisfy domestic demand; biofuel surpluses are assumed to be exported through the Vancouver port. Next, the associated rail costs are computed and apportioned back to the farmer. Biofuel prices are computed as a function of crude oil prices and petroleum prices. Processing margins are deducted and the resulting price is the return to biofuel cropping before transportation and production costs have been subtracted.

As shown in Figure 3.1, production quantities in the *FARMCHAIN* model's logistic chain moves from the farm level to the ports (bottom-up) while information, in the form of prices and costs, is transmitted from the top-down. The ensuing sections first describe the role of agents in the model according to the bottom-up movement of crops, starting with the landscape, then the farmers and finally the alternate distribution channels. Thereafter, the top-down information flow of prices, costs and expectations are discussed in a context of how the model transitions into the following period.

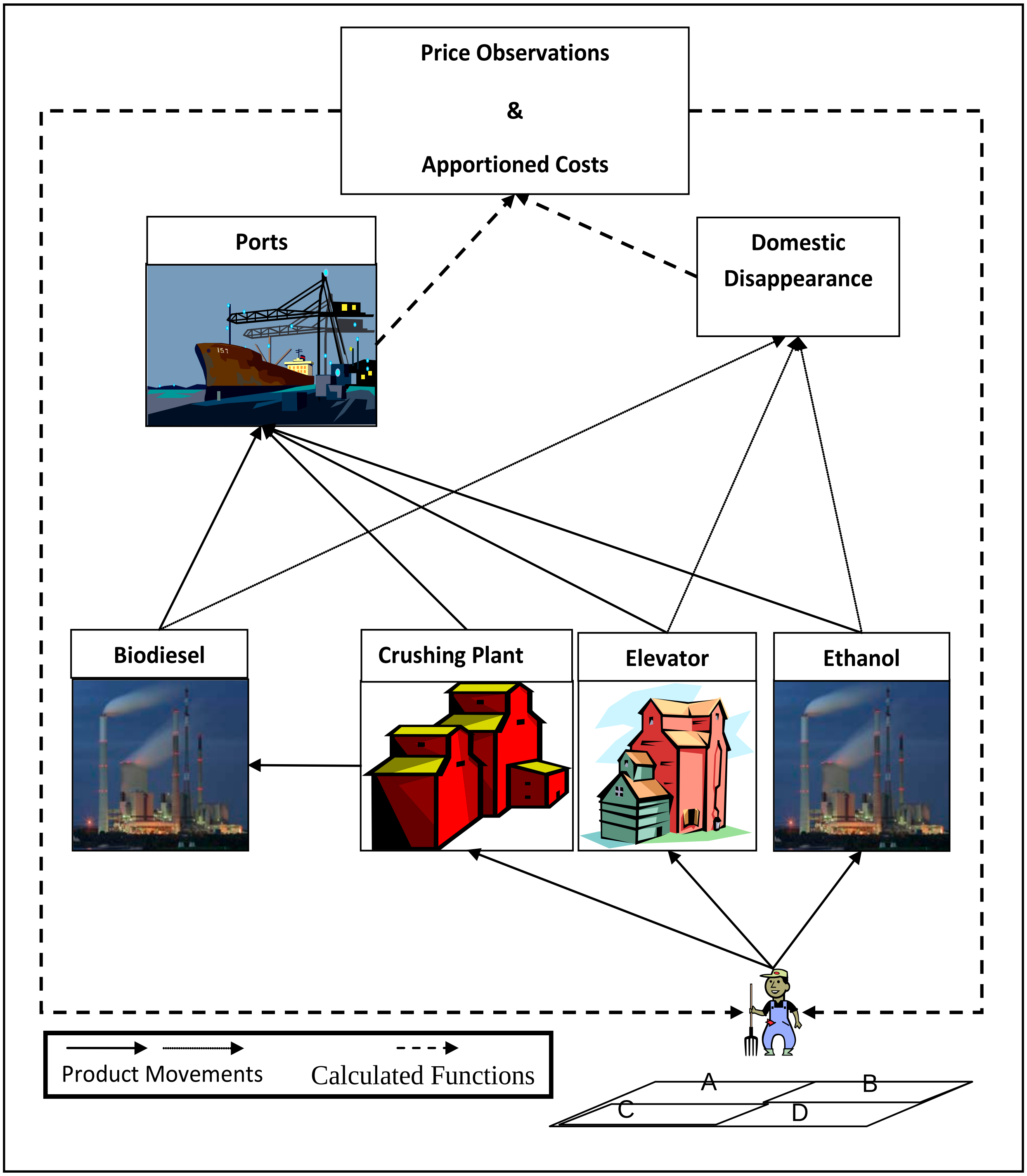

Figure 3.1: Simplified *FARMCHAIN* Flow Diagram.
Source: Created by author

3.2.2 Landscape

The *FARMCHAIN* model geographically represents the agricultural production landscape of the 20 Census Agricultural Regions (CARs) in Saskatchewan. The model landscape is comprised of 106,346 patches, of which 757 patches represent water masses and are therefore excluded from the model. A patch covers approximately 1,964 acres of Saskatchewan agricultural land.[10] Patches contain CAR identification information, soil zone information, production and crop production cost coefficients. The landscape layer contains the information used in characterizing their associated farmer agents.

3.2.3 The Farmer Agents

Each farmer agent is randomly "sprouted" from the landscape and is assigned the characteristics of its associated patch. For replication purposes, the randomly sprouted farmer agent is created based on a random seed algorithm. The *FARMCHAIN* model sprouts 36,952 farmers, the number of farmers that reported in the 2011 Census of Agriculture (Statistics Canada, 2012), and is allocated in the same fashion for respective CARs.

Pivotal to the model results are the farm-level production decisions. These decisions are influenced by the differing farmer agent characteristics. Farmer agents are heterogeneous based on farm size, location and price expectations. Farm size is exogenously computed and is constant for all replications. Farmer agent farm size is randomly assigned and is uniformly distributed around the mean farm-size of farmers of each of their respective CARs. The total land-size of farmers approximately reflects the total seeded acreage in 2010 of spring wheat, canola, barley and field peas. Farmers also differ in their location.[11] That is, they not only differ in their proximity to grain elevator agents, ethanol plant agents and crushing plant agents but they also may differ based on the soil zone in which they are situated. Differences in soil zones may imply differences in cost of production and crop yield coefficients, thus increasing farmer agent

[10] The patch size is computed as the approximate area of all 20 CARs divided by the number of patches in that fall within the 20-CAR boundary shapefiile. The approximate area is obtained from ArcGIS area tool.

[11] The model represents the location of the farmer agent as a reference point of crop delivery and does not geographically represent the spatial construct of a bounded farm. To ensure no overlap a patch is larger than the largest farm size in the model. This means for every patch that has a farmer there would be unutilized land.

heterogeneity.[12] Farmers also differ in their formulation of expected prices from one time period to another. The following section explains how farmers formulate their expectations.

3.2.3.1 Price Expectations

Ezekiel (1938) proposed that farmer expectations were as a result of previous period's price observations. Nerlove (1958) expanded this noting that price expectations not only depend on prior price observations but also can adapt to previous forecast errors. The rational expatations literature arose highlighting expectations do not only incorporate lagged price information but all the information relevnt to the formulation of expectations and could include futures prices (Muth, 1961). Sulewski, Spriggs and Schoney (1994) however show that even though lagged-price models and futures prices are accurate indicators of future commodity prices, it inadequately captures Canadian farmers' expectation formulation for wheat and canola. In the *FARMCHAIN* model it is assumed that farmer agents formulate price expectations following a variant of the rational expectations literature, where expected prices are a stochastic function of past and expected future prices. That is, the model's farmer agents express their price expectations as a weighted average of gross margins earned in period t and an estimate of the future gross margins yet to be observed in period $t+1$. The estimate of the future gross margin is given by the expected world price in period $t+1$ less the realized variable costs (variable production costs and costs associated with storage and handling) of period t. It is assumed that farmer agents are also heterogeneous differ according to their view of markets. A farmer that is more forward looking would have a higher weight on future expectations of gross margins. However, if the farmer has a greater weight on realized gross margins, the farmer believes that past performance is a better indication of future performance. The expectations formulation is expressed as:

$$\begin{aligned} &Expected\ Gross\ Margin_{t+1}^{j} \\ &= \left[(1-\varphi^{n}) \times Gross\ Margin_{t}^{j} + \varphi^{n} \times (World\ price_{t+1}^{j} - Variable\ Cost_{t}^{j})\right] \\ &\qquad \times Yield^{j,l} \qquad \ldots (1) \end{aligned}$$

[12] Crop yields are assumed to be static and differ only by location.

Thus expected prices differ for the j^{th} crop, across the n^{th} farmer agent, over t^{th} time period and for farmers in the l^{th} location. The weight, φ^n, used in the price expectations formulation is exogenously created and follow a uniformly random distribution with values between 0 and 1. Therefore as $\varphi^n \rightarrow 1$, the n^{th} farmer agent is more forward looking. However, in the initial period $t = 0$ farmers' crop expectations are equal to the world crop prices of the period, while biofuel wheat expected crop price at period $t = 0$ is zero. The farmer agent's expected price influences the crop land allocation.

3.2.3.2. Land Allocation

Farmer agents make land-use and transportation decisions based on economic and agronomic considerations. The farmer agent allocates land to four crops: wheat, canola, barley and field peas. The farmer decides whether to seed spring wheat or biofuel wheat. Since spring wheat and biofuel wheat are assumed to be perfect agronomic substitutes and the farmer agent can switch between the two wheat types at zero cost.

Following a variant of Oglethorpe (1995), farmer agents maximize expected crop returns subject to agronomic or resource constraints:

$$Max\ Expected\ Gross\ Margin\ = \sum_{j=1}^{5} Expected\ Gross\ Margin^j \times Land^j \times Yield^j \quad \text{... (2)}$$

$$Subject\ to:$$

$$A \times Land \leq b \quad \text{... (3)}$$

Where A represent the matrix of agronomic coefficients and $Land$ represents the vector of land allocation variables and b is a vector containing the right-hand-side (RHS) of resource limits. j denotes the j^{th} crop. The model can explicitly be written to show the rotational problem and the sub problem of the wheat types. Therefore equations (2) and (3) may be expressed as:

$$Max\ Z = R_w X_w + R_b X_b + R X_c + R_p X_p \quad (4)$$

$$s.t.:\ X_w + X_b + X_c + X_p\ \leq acres$$

$$X_c\ \leq \alpha_c acres$$

$$X_p\ \leq \alpha_p acres$$

$$R_w X_w = Max[\, R_{SW} X_w^{SW},\ R_{FW} X_w^{FW}] \quad (5)$$

where $w = wheat, b = barley, c = canola, p = field\ peas, R =$ expected gross margin

$\alpha_c = maximum\ percent\ of\ canola, \alpha_p = maximum\ percent\ of\ field\ peas$

$Max[\, R_{SW} X_w^{SW},\ R_{FW} X_w^{FW}] = subproblem, X = the\ portion\ of\ land\ allocation$

A linear programming problem is a method of "allocating resources to activities" (Hillier and Lieberman, 2001, p.153). In this case farmer agents are seeking to allocate their land resource to competing crops. An analysis of relative historical allocations of the spring wheat, canola, barley and field peas as shown in Figure 2.6, reveals that canola and wheat compete with each other for the acreage majority while peas and barley compete at lower proportions. Utilizing this information in modelling, it is assumed that the number of basic feasible solutions (BFS) could be reduced to a very limited, finite, discrete set. The *FARMCHAIN* model uses 8 BFS and selects the option that maximizes each farmer agent's expected return as seen in equation (1). These eight BFS are called solution packages and the optimal solution is determined through a three-stage iterative process.

In the first stage of the iteration process the farmer agent solves the sub-problem indicated in section 3.2.1 by ranking expected returns for food wheat (SW) and biofuel wheat (FW). As shown in Table 3.1 basic feasible solutions 1 through 4 food wheat is produce instead of biofuel wheat and the opposite is true for basic feasible solutions 5 through 8. In the second stage farmer determine land allocations to the four crops. Farmers compare the gross margins of canola, dry peas, barley and wheat (the wheat-type selected from the sub-problem) to determine how much land is allocated between the four crops. The land proportion of wheat to seed relative to canola is then determined based on the expected gross margins of wheat to relative to canola.

Concurrently, the farmer agent determines the proportion of land to seed barley relative to field peas based on the comparison of their expected gross margins. In the final stage farmers selects one of eight basic feasible solutions that maximise their expected returns. The selected acreages are summed and relative proportions computed. These relative proportions become BFS1 as shown in Table 3.1. The relative proportions or land allocation ratios are the same as the production coefficients in the discussed in Section 3.2.2 and they differ by CAR.

Table 3.1: *FARMCHAIN* Model Optimal Solution Selection Process

STEP 1: DECIDE TYPE OF WHEAT	STEP 2: DETERMINE 4-CROP ALLOCATION	STEP 3: SOLUTION PACKAGE	
If Exp. Ret(SW) >Exp. Ret(FW)	If Exp. Ret(SW) >Exp. Ret(CAN) and If Exp. Ret(BAR) >Exp. Ret(FP)	BFS 1	FW=0; MAX: SW, BAR; CORRESPONDING: CAN, FP
	If Exp. Ret(SW) >Exp. Ret(CAN) and If Exp. Ret(FP) >Exp. Ret(BAR)	BFS 2	FW=0; MAX: SW, FP; CORRESPONDING: CAN, BAR
	If Exp. Ret(CAN) >Exp. Ret(SW) and If Exp. Ret(BAR) >Exp. Ret(FP)	BFS 3	FW=0; MAX: CAN, BAR; CORRESPONDING: SW, FP
	If Exp. Ret(CAN) >Exp. Ret(SW) and If Exp. Ret(FP) >Exp. Ret(BAR)	BFS 4	FW=0; MAX: CAN, FP; CORRESPONDING: SW, BAR
If Exp. Ret(FW) >Exp. Ret(SW)	If Exp. Ret(FW) >Exp. Ret(CAN) and If Exp. Ret(BAR) >Exp. Ret(FP)	BFS 5	SW=0; MAX: FW, BAR; CORRESPONDING: CAN, FP
	If Exp. Ret(FW) >Exp. Ret(CAN) and If Exp. Ret(FP) >Exp. Ret(BAR)	BFS 6	SW=0; MAX: FW, FP; CORRESPONDING: CAN, BAR
	If Exp. Ret(CAN) >Exp. Ret(FW) and If Exp. Ret(BAR) >Exp. Ret(FP)	BFS 7	SW=0; MAX: CAN, BAR; CORRESPONDING: FW, FP
	If Exp. Ret(CAN) >Exp. Ret(FW) and If Exp. Ret(FP) >Exp. Ret(BAR)	BFS 8	SW=0; MAX: CAN, FP; CORRESPONDING: FW, BAR

Source: Constructed by author

3.2.3.3 Actual Farm Production and Production Costs Computation

After farmers have decided cropland allocation in the t^{th} period, they produce, store crops for ready for transport to market and compute actual production costs. Total farm production is computed as the land allocation ratio multiplied by the land-size multiplied by yield associated with the location of the farmer. This can be written more formally as:

$$Q_t^j = Land\ ratio_t^j \times Land\ size \times yield^{j,l} \qquad \dots (6)$$

where $Land\ ratio_t^j$ is the allocation ratio at time period t for crop j. Land size is the total number of acres the farmer has to cultivate and $yield^{j,l}$ is the yield in tonnes per acre for crop j associated with the farmer operating in the l^{th} location. Production costs are computed as a function of the soil zone in which the farmer is located and represent the total variable cost of production.

Initially in time period $t = 0$, the unit production cost is given by:

$$UCOP_0^j = TVC^{j,l} \qquad \dots (7)$$

Where TVC is the total variable cost per acre of producing crop j in the l^{th} location

For $t > 0$, the unit production cost is given by:

$$UCOP_t^j = UCOP_{t-1}^j + Fuel_0^j \times (\varepsilon^{fuel} \times \%\Delta Oil\ Price) + Fertilizer_0^j \times \left(\varepsilon^{fertilizer} \times \%\Delta Oil\ Price\right) \qquad \ldots (8)$$

Where $UCOP_{t-1}^j$ is the total variable cost per acre (later converted to a cost per tonne) in the previous period for the j^{th} crop, $Fuel_0^j$ is the initial fuel cost component, ε^{fuel} represents the pass-through of oil prices to fuel prices, $\%\Delta Oil\ Price$ is the real annual growth in crude oil price per barrel, $Fertilizer_0^j$ is the initial fertilizer cost component and $\varepsilon^{fertilizer}$ represents the pass-through of oil prices to fertilizer prices.

The total variable cost of production is given by:

$$COP_t^j = UCOP_t^j \times Land\ size \qquad \ldots (9)$$

The total variable cost of production is converted to total variable cost per tonne by dividing total variable cost associated with the j^{th} crop by the total production of the j^{th} crop.

3.2.3.4 Crop Storage, Trucking Choice and Trucking Costs

After the crop is produced, it is stored on the farm. It is assumed that there are no capacity constraints in on-farm storage and that the on-the-farm storage costs are fixed at zero. At this stage, farmers now consider distribution channels. That is, farmers determine whether the crop has to be trucked to grain elevators, crushing plants or an ethanol plant. Food wheat, barley and field peas are trucked to grain elevators, canola goes to either elevators or crushing plants and biofuel wheat goes to ethanol plants.

In order for a farmer to choose an elevator, the farmer first counts the number of elevators within a pre-determined trucking threshold. If there is at most one elevator within the threshold, then the farmer delivers the crop to the closest elevator. If there is more than one elevator within this threshold, the farmer delivers the crop to the elevator with the lowest storage and handling costs. This decision holds for wheat, barley and field peas. For canola, farmers transport the seed to the nearest elevator or crushing plant and biofuel wheat is trucked to the nearest ethanol plant.

When the farmer decides the destination of the crop, the crop is then transferred to that destination and the trucking cost computed. Following Lawrence (2011), total trucking cost is a function of trucking distance, the amount of crop j in storage to be hauled and fossil fuel prices and is given by:

$$Truck\ Cost_t^j = \left[\left(\alpha^j + \ truckdistance_t^j\ \times\ \beta^j\right) \times\ Storage_t^j\right] \times [1 + \%surcharge_t]\ \ldots (10)$$

The trucking cost is comprised of α^j and β^j – linear parameters of the unit cost of trucking crop j, $truckdistance_t^j$ - the Euclidean distance between the farmer and the elevator, crushing plant or ethanol plant chosen by the farmer, $Storage_t^j$ - farmer's storage of harvested crop j to be transported by truck in time period t and $\%surcharge_t$ – trucking surcharge applied in t^{th} period. The trucking surcharge rate is computed as:

$$\%surcharge_t = \ \%surcharge_{t-1}\ \times [1 + (\%\Delta Oil\ Price\ \times \varepsilon^{surcharge})] \qquad \ldots (11)$$

The surcharge in period t is equal to the surcharge of the previous period grown at the rate of change of oil prices multiplied by $\varepsilon^{surcharge}$, the elasticity of trucking surcharge rate to changes in oil prices.

3.2.4 Distribution Channels

Farmer agents in the *FARMCHAIN* model are at the start of the crop supply chain and must deliver crops produced to the marketing channel assigned to the crop. As seen in Figure 3.1, the network of crop movement thereafter either moves to port or exits the *FARMCHAIN* model by assuming that it has been used for domestic consumption and is valued at the world price. The exception is canola. Canola is sent to both elevators and crushing plants. At the crushing plant, canola undergoes additional processing with the export portion railed to ports and the domestic portion forwarded the biodiesel plant for further processing. The following sections further explain the structural operations of each agent type in the rest of the supply chain.

3.2.4.1 Grain Elevators

Elevator agents seek to maximize handling fees while farmers seek to minimize handling costs and elevator agents learn from their interactions with farmers and other elevators within close proximity in order to estimate their own fees. In the *FARMCHAIN* model, it is assumed that grain elevators are spatially competitive. It is also assumed that grain elevators influence the farmgate return to farmers through their elevation, cleaning and storage (handling) fees. It is also assumed that elevators compete for farmers' harvest crops using spatial Bertrand price competition: elevators employ an undercutting price strategy in order to maximise grain throughput relative to other elevators in close proximity. As such, the higher the number of rival elevators, the lower the handling fees charged by the elevator. These fees are assumed to be proxies of the financial health of elevators in that the higher the fees charged by an elevator, the more financially viable is that elevator. Furthermore, it is assumed that an elevator discontinues operation if its competitive handling fees fall to zero for all four crops received in a given time period. The fee charged by an elevator increases if the amount of crop transported to the elevator exceeds the average crop transported to elevators within a predefined proximity radius (called close proximity), decreases if the amount of crop transported to the elevator is less than the average crop transported to elevators within close proximity and remains the same if it is equal to the average crop transported to elevators within close proximity.

It is also assumed that elevators do not have capacity constraints. Thus one elevator could handle all the grain or none of it. In addition, it is also assumed that crops trucked to elevators, with the exception of canola, will be either moved to port or exits the *FARMCHAIN* model and assumed to be used for domestic consumption valued at the world price. It is further assumed that all the canola trucked to elevators is forwarded directly to the ports. Most of the exports crops from the prairies are shipped through Prince Rupert, Vancouver, Thunder Bay or Churchill. However because the Prince Rupert port is so far from Saskatchewan elevators and historically very little has moved through Churchill (CGC, 2011; CGC, 2008), the *FARMCHAIN* model only uses the Vancouver (West) and Thunder Bay (East) ports. Rail costs are then computed for crops and given:

.

$$Rail\_cost_t^j = \left(ExportQty_t^j * \frac{Railcost}{tonne} * Adj_{factor} * \ Distance^p\right) \times (1 + \%surcharge_t) \qquad \ldots (12)$$

Where $ExportQty_t^j$ denotes the export supply in tonnes in period t of the j^{th} crop, Adj_{factor} is an adjustment factor that is used to calibrate rail costs.[13] $Distance^p$ denotes the geodesic distance of the elevator to the port in the p^{th} location. Rail costs increase annually at the rate of the rail surcharge rate. The rail surcharge rate is assumed be equal to the trucking surcharge rate.

The associated rail cost to farmers for a given crop for a given period is apportioned by calculating the amount of crop transported to that elevator in that period divided by the total amount of crop that is delivered to that elevator in that period multiplied by the total rail cost computed for that elevator.

3.2.4.2 Canola Crushing Plants

The model assumes that canola is transported to a crushing plant if the farmer is closer to a crushing plant than an elevator. Similar to the elevators, it is assumed that there are no capacity constraints. It is also assumed that crushing plants do not directly spatially compete with elevators for canola. Another assumption is that crushing plants deduct a constant processing margin in excess of handling and storage fees charged to farmers. The canola crop at the crushing plant is processed and then transported via rail to the ports and to the biodiesel plant. Each crushing plant has built-in the distance to the two ports and the distance to the biodiesel plant.

Like elevators, rail costs at the crushing plant are apportioned to the farmer based on the canola transported to that crushing plant divided by the total crop delivered to the plant in that period multiplied by the total rail costs associated with the crushing plant.

3.2.4.3 Biodiesel Plant

Canola oil is transported via rail from crushing plants to the biodiesel plant. It is assumed that there are no capacity constraints for processing canola oil. Canola oil is processed into biodiesel and is first used to meet domestic mandated amounts. Domestic demand for biodiesel is a

[13] The rail cost per tonne used in Nolan and Carlson (2005) is not reflective of costs in 2010. Therefore the adjustment factor captures the scale of calibration to the Nolan and Carlson estimates.

derived demand from the local diesel fuel oil demand. The local diesel demand which is estimated as a linear function of time is given by:

$$Dieseldemand_t(litres) = \theta \ + (\mu * year) \quad \ldots (13)$$

where μ and θ are estimated coefficients

The corresponding biodiesel demand is the mandated amounts. That is, the percent mandate is multiplied by the diesel demand in the period:

$$Biodieseldemand_t = Biodiesel\_mandate\% * Dieseldemand_t \quad \ldots (14)$$

If production exceeds mandated amounts then the excess is assumed to be transported via rail to Vancouver for export. The rail cost for the biodiesel plant is computed and given by the following function:

$$Rail\_cost_t^{BD} = \left(BDQty_t * \frac{Railcost}{tonne} * Adj_{factor} * Distance^{Vancouver} * \omega^{BD}\right) \times (1 + \%surcharge_t) \quad \ldots (15)$$

where $BDQty_t$ is the surplus biodiesel produced in litres in period t and $\omega^{BD}$is the conversion factor of litres of biodiesel to tonnes.

The rail costs are then apportioned to farmers who sent their grain to the canola crushing plant based on the farmers' relative share of the crop sent to the crushing plant and the relative share of the canola oil supplied to the biodiesel plant relative to the total canola oil supply to the biodiesel plant.

3.2.4.4 Ethanol Plants

Industrial wheat is trucked directly to the ethanol plants. It is assumed that there are no capacity constraints for processing the grain. Grain is processed into ethanol and is used to meet domestic mandated amounts. Domestic demand for ethanol is a derived demand from the demand for local gasoline. Local gasoline demand is estimated as a linear function of time and is given by:

$$gasdemand_t(litres) = \gamma + (\delta \times year) \quad \ldots (16)$$

where γ and δ are estimated coefficients

The corresponding ethanol demand is the mandated amounts:

$$ethanoldemand_t = (ethanol\_mandate\%) * gasdemand_t \quad \ldots (17)$$

If production exceeds mandated amounts then the excess is transported by rail to Vancouver for export. The rail cost for ethanol plants is computed and given by the following function:

$$Rail\_cost_t^{Eth} = \left(EthQty_t * \frac{Railcost}{tonne} * Adj_{factor} * \ Distance^{Vancouver} * \omega^{Eth}\right) \times \ (1 + \%surcharge_t) \quad \ldots (18)$$

where $EthQty_t$ is the surplus ethanol produced by the ethanol plant in litres in period t and $\omega^{Eth}$is the conversion factor of litres of ethanol to tonnes. The rail cost is thereafter apportioned to farmers who sent their grain to the ethanol plant.

3.2.4.5 Ocean Freight Computation

Products slated for export are assumed to be transported by ship from the port to the export country. In order to obtain farmgate prices an estimate of ocean freight costs must be computed. It is assumed that products shipped through western port are destined for Japan while products shipped through the eastern ports are destined for Venezuela.[14] The ocean freight rate per tonne of export product (export crop or export biofuel) slated for transport to d^{th} destination in time period t can be expressed as:

$$OceanFreight\ Rate_t^{j,d} = OceanFreight\ Rate_{t-1}^{j,d} \ \times \left[1 + \left(\%\Delta Oil\ Price\ \times \varepsilon^{freight}\right)\right] \quad \ldots (19)$$

where $\varepsilon^{freight}$ is percentage change ocean freight rate due a 1% change in oil price and is the elasticity estimate obtained from Hummels (2007).

The total ocean freight cost for the j^{th} export produce that goes either east or west is given by:

$$OceanCost_t^j = \ ExportQty_t^{j,west} \ \times OceanFreight\ Rate_t^{west} + ExportQty_t^{j,east} \times OceanFreight\ Rate_t^{east} \quad \ldots (20)$$

where $ExportQty_t^{j,d}$ represents crop export quantity in tonnes or the converted tonne equivalent of litres of biofuel destined for export.

3.2.5 Computation of Gross Margins

[14] The South American continent was selected because most wheat shipments in the crop year 2010-2011 were destined for the western hemisphere, with Venezuela receiving the most shipments (CGC, 2011).

Since crops are transported from the farm level through the ports (bottom-up) as shown in Figure 3.1, information in the form of prices and costs move from the top of the model down to the farmer. At the end of a simulation period, farmers observe crop and biofuel prices, costs of production, processing and handling to compute their gross margins. The following sections discuss price observations and the computations of gross margins in the *FARMCHAIN* model.

3.2.5.1 Price Observations

It is assumed that world crop prices are exogenously determined for spring wheat, barley, canola and field peas. Biofuel prices are assumed to be determined based on the energy equivalent price of their fossil fuel counterparts. Following Tyner and Taheripour (2007), gas price is linear function of the crude oil price:

$$pgas_t = \rho^{gas} + (\sigma^{gas} \times crudeprice_t) \qquad \dots(21)$$

where $crudeprice_t$ is the price of crude oil in period t. ρ^{gas} and σ^{gas} are estimated scalars.

Tyner and Taheripour (2007) proposed a proportional conversion of gas prices and ethanol prices, noting that ethanol prices are approximately the energy equivalent of gas prices. The *FARMCHAIN* utilizes this principle but uses the conversion factor implied by Pimentel, Patzek and Cecil (2003) (described in the next chapter) and adds a variable that captures government ethanol policy impacts. Thus the energy equivalent price adjusted for ethanol processor returns of ethanol is given by:

$$peth_t = (\tau^{ethanol} \times pgast_t + ethanolsubsidy) \times (1 - \pi) \qquad \dots(22)$$

Where $\tau^{ethanol}$ is a scalar parameter and $ethanolsubsidy$ is the cent per litre government support to the ethanol plant and π represents the percent sales margin to ethanol producers. The ethanol plants are assumed to deduct a margin which is a function of oil-prices:

$$eth\,margin_t = eth\,margin_{t-1} + \left(\aleph^{ethanol} * (1 + \varepsilon^{fuel} \times \%\Delta Oil\,Price)\right) \qquad \dots(23)$$

where $\aleph^{ethanol}$ is the portion of ethanol non-feedstock production costs that is attributable to fuel. Similarly, the diesel price is a linear function of world crude oil prices given by:

$$pdiesel_t = \left(\rho^{diesel} + \sigma^{diesel} \times crudeprice_t\right) \qquad \dots(24)$$

where ρ^{diesel} and σ^{diesel} are estimated coefficients.

As in the case of ethanol plants, the model assumes that the price of biodiesel is the energy equivalent of price of diesel fuel. This model adds a variable subsidy in cents per litre such that the price of biodiesel adjusted for processor returns is given by:

$$pbiod_t = (\tau^{diesel} \times\ pdiesel_t + biodieselsubsidy)\ \times (1 - \pi) \qquad \ldots(25)$$

where τ^{diesel} is an estimated coefficient and $biodieselsubsidy$ is the cent per litre government support to the biodiesel plant and π represents the percent sales margin to biodiesel producers. The biodiesel plant is assumed to deduct a margin which is a function of oil-prices:

$$biod\ margin_t =\ biod\ margin_{t-1}\ +\ \left(\aleph^{diesel}\ *(\ \varepsilon^{fuel} \times\ \%\Delta Oil\ Price)\right) \qquad \ldots(26)$$

Where $\aleph^{diesel}$ is the portion of biodiesel non-feedstock production costs that is attributable to fuel.

3.2.5.2 Computation of Farmer Gross Margins

After the prices have been obtained, farmers compute their gross margins that are equal to the world price of the crop less the variable cost of crop production, transportation, handling and storage. In periods in which the farmer agent does not produce biofuel wheat, a biofuel memory variable (FW_MEMORY) recalls the last estimated cost of production per tonne that is incurred for producing biofuel wheat. Similarly, there is a spring wheat memory variable (SW_MEMORY) that farmer agents utilize if spring wheat production for that farmer is zero. Furthermore, it is assumed that there is no biofuel production in the first period.[15] In this case, the farmer agent sets the biofuel memory variable equal to the total production and trucking costs of spring wheat in that period.

In periods where the farmer agent does not produce biofuel wheat, the farmer agent's hypothetical gross margin is equal to ethanol price less the processing margin less FW_MEMORY. Conversely, if the farmer agent does not produce spring wheat then the farmer agent's hypothetical gross margin is the world price of wheat minus SW_MEMORY. The gross margins are used to compute the expected returns for the next period.

3.3 Summary

[15] The model uses the first four periods for initializing the model to reduce initialization effects.

This chapter outlined the design of the *FARMCHAIN* model. The model comprises five types of agents: farmers, grain elevators, ethanol plants, biodiesel plant and canola crushing plants. The role of each agent type was outlined and rules and assumptions governing behaviour and inter-agent interactions were also stated. Pivotal to the *FARMCHAIN* model results are the land use decision of farmers. This chapter outlined the general framework under which farmer agents made their cropping decisions, of how crops moved through supply/value chain to the port to be exported to foreign destinations and how prices were observed and costs apportioned to the farmer. Chapter 4 provides parameter estimates for the structural and behavioural equations outlined in this chapter. This includes data used in characterizing the agents and the landscape. Also, the following chapter provides values for the model initialization as well as descriptions of global variables in the model and how there were generated.

CHAPTER 4: *FARMCHAIN* DATA, PARAMETERIZATION AND INITIALIZATION

4.1 Introduction

The previous chapter described the flow of the *FARMCHAIN* model, outlining the structural and functional relationships between agents in the supply chain. This chapter specifies the model initialization, the various structural coefficients, prices and yield coefficients.

4.2 The Landscape

The Saskatchewan landscape is heterogeneous, differing in arable land, crops commonly grown and associated yield potential and cost of production. These patches contain land quality and land use allocation coefficients, yields and associated costs of production.

4.2.1 Patch Soil Quality, Yield and Cost of Production

Unfortunately geographic information system (GIS) data are unavailable to meet all patch data requirements. In the case of spring wheat[16], barley and canola yields and land quality, a shapefile exists (AAFC, 2008). In Figures 4.1 through Figures 4.3, the spatial patterns of average yields are displayed for spring wheat, barley and canola, respectively. Unfortunately, this database does not include field peas and there are some areas which have no yield information assigned; accordingly, field pea yields and areas without yield information are assigned yields based on the 2012 Crop Planning Guide soil type area averages. Costs of production are also assigned to patches based on soil zones (Table 4.1). These are remapped based on soil zone (Figure 4.4) to the land quality boundaries as displayed in Figures 4.1 - 4.3.

[16]Wheat yields from the shape file are generic to all wheat. Biofuel wheat yield is assumed to 1.07 times that of spring wheat as computed from the 2012 Crop Planning Guide (Saskatchewan Ministry of Agriculture, 2012b).

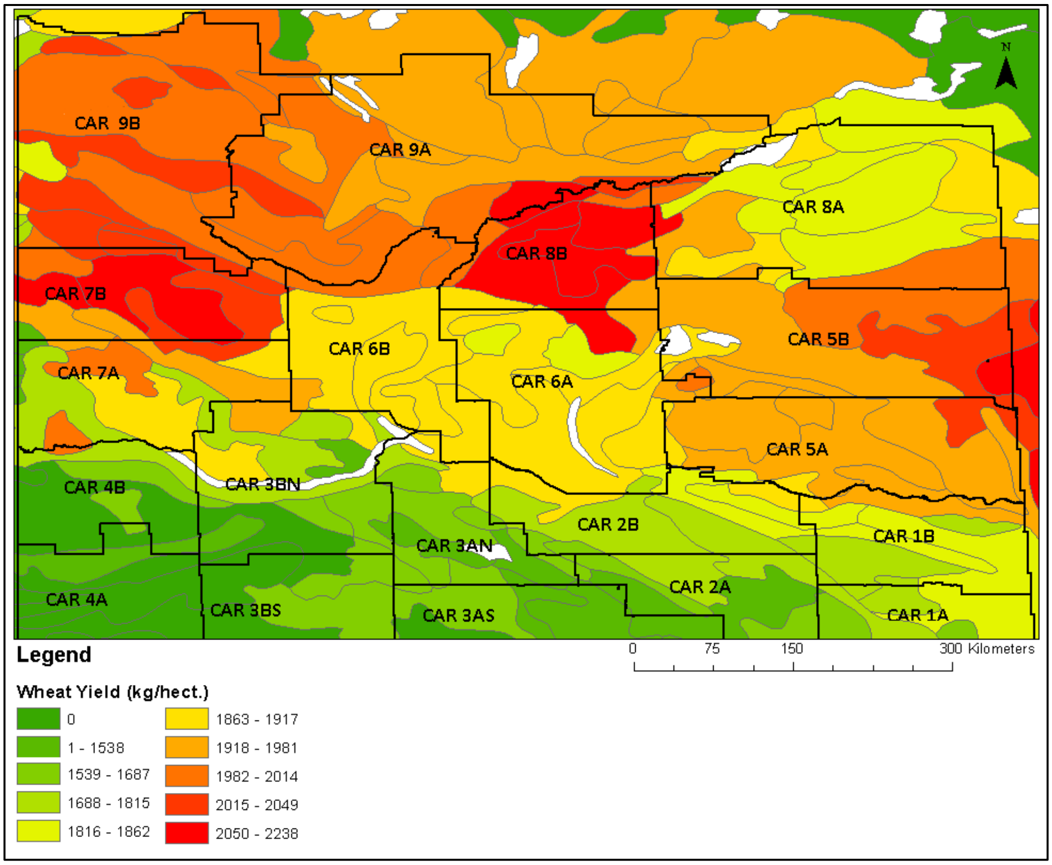

Figure 4.1: Saskatchewan Spring Wheat Yield by Census Agricultural Region
Source: Created by author with data from Land Potential Database (AAFC, 2009).

It is important to note the spatial heterogeneity that exists within a CAR. This may impact the farmer agent gross margins and ultimately land allocation decisions. This is shown in Figure 4.1, where CARs 5A, 5B, 7B, 8B, 9A and 9B have the highest wheat yields but the southwestern CARs have the lowest yields. This pattern is also consistent for Figures 4.2 and 4.3.

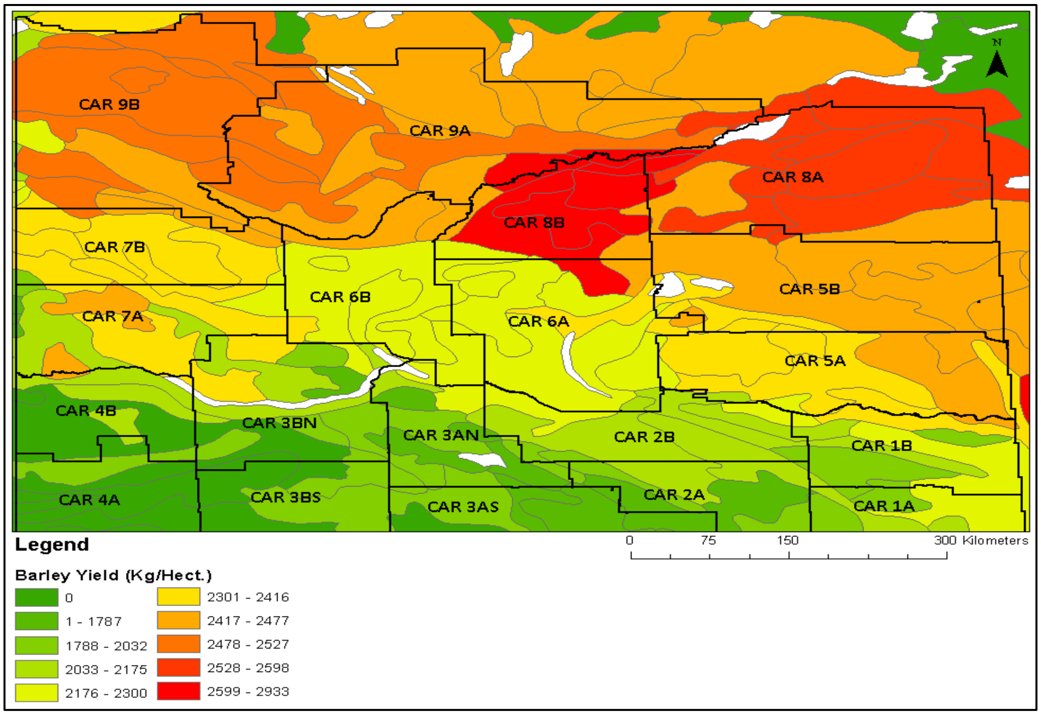

Figure 4.2: Saskatchewan Barley Yield by Census Agricultural Region
Source: Land Potential Database (AAFC, 2009).

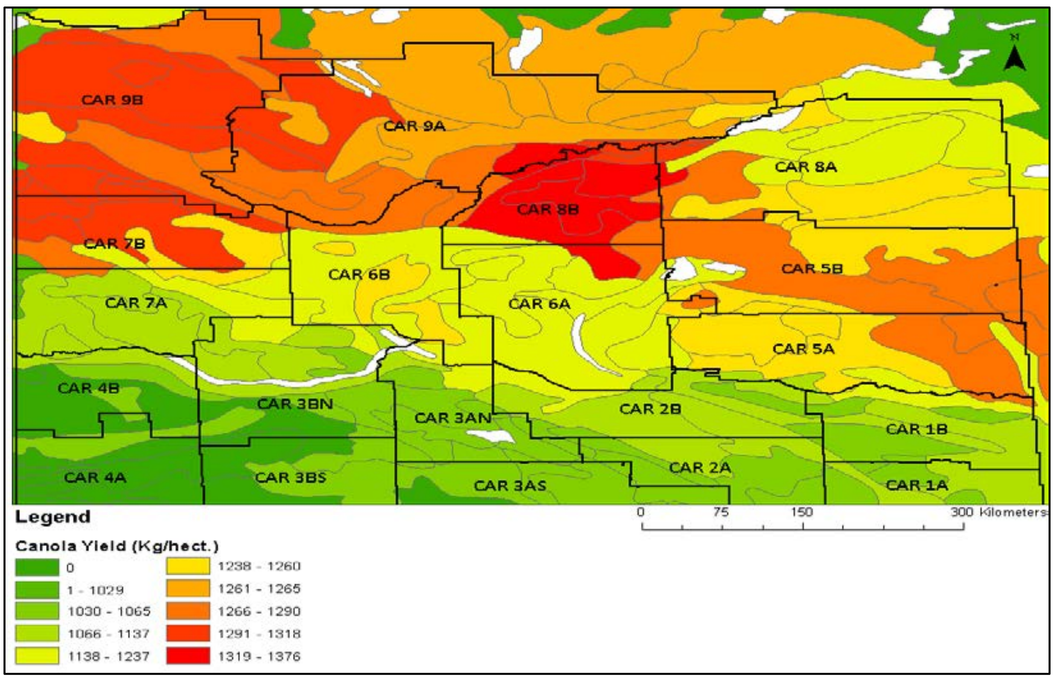

Figure 4.3: Saskatchewan Canola Yield by Census Agricultural Region
Source: Land Potential Database (AAFC, 2009).

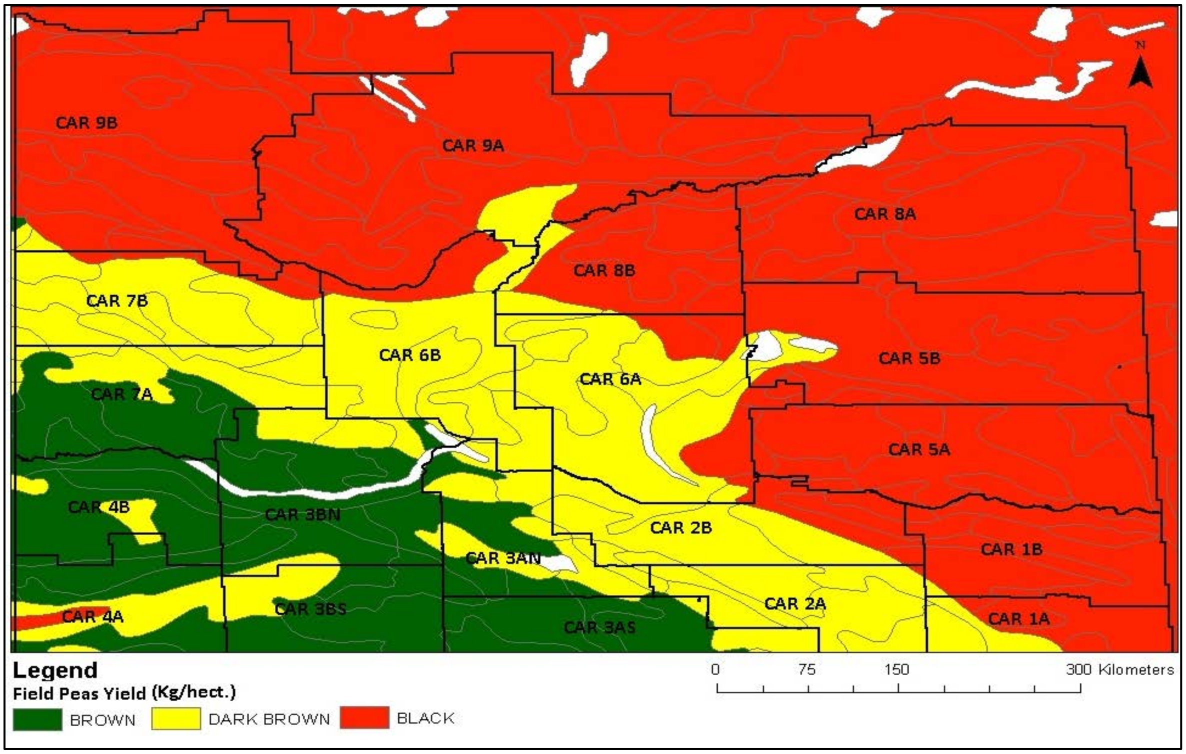

Figure 4.4: Saskatchewan Soil Zones
Source: Land Potential Database (AAFC, 2009) and Saskatchewan Ministry of Agriculture, 2012b.

Table 4.1: Yield and Production Cost data by Crop by Soil Zone

Crop	Soil Zone	Yeild (t/acre)	Fertilizer Cost ($/acre)	Fuel Cost ($/acre)	Total Variable Costs
Hard Wheat	Brown	0.81	38.85	16.66	145.98
	Dark Brown	0.93	50.25	16.66	168.10
	Black	1.14	46.90	16.66	171.36
Soft Wheat	Brown	0.89	38.85	16.66	145.98
	Dark Brown	1.14	50.25	16.66	168.10
	Black	1.40	46.90	16.66	171.36
Canola	Brown	0.53	40.20	17.64	205.32
	Dark Brown	0.75	50.25	17.64	209.90
	Black	0.83	46.90	17.64	202.79
Barley	Brown	1.06	33.50	16.66	140.11
	Dark Brown	1.33	56.95	16.66	179.46
	Black	1.54	43.55	16.66	156.46
Field Peas	Brown	0.86	4.02	18.62	128.34
	Dark Brown	1.00	4.02	18.62	126.09
	Black	1.01	4.02	18.62	141.23
Soft wheat (biofuel wheat) total variable cost of production is assumed to be the same as that of hard wheat (food wheat). This assumption is consistent with the assumption of costless switching between the two wheat types.					

Source: Saskatchewan Ministry of Agriculture 2012b.

4.2.2 Production Packages (Land Allocation Ratios)

Another shapefile outlines the boundary of the CAR and contains unique land use allocation coefficients or production packages (as outlined in Chapter 3). The land allocation coefficients, which can be found in Table B-1 of Appendix B, are transferred to the patches and specify the percentage of land allotted for each crop in each patch.

4.2.3 Farm Location

Another integral part of the landscape is the farm agent location. Farmers are initially randomly distributed across the CAR but once their location is assigned, it is kept constant across simulation replications and scenarios. Initial assignment is based on a random seed algorithm. In comparison to the ABM models of Freeman (2005), Stolnuik (2008) and Anderson (2012), *FARMCHAIN* farmers are relatively simple and are differentiated only by farm land size, location and price expectations. In order to demonstrate the assignment process, two numbers; 100 and 98,238, are chosen at random to be the random seeds. The resulting farm assignments are displayed in Figures 4.5 and Figures 4.6, respectively. In Figures 4.5 and 4.6 five farmer agents are selected at random; farmer 5 (orange), farmer 33,500 (red), farmer 9,108 (yellow), farmer 15,000 (pink) and farmer 25,000 (green).[17] Freeman found that farm assignment does not result in path dependency. Nevertheless, this hypothesis will be tested and further discussed in Chapter 5.

[17] All patches are the same size and each patch represents 1964 acres. A farmer is "sprouted" from a patch that is selected at random without replacement and his land size is at most 1825 acres, which is less than the patch size.

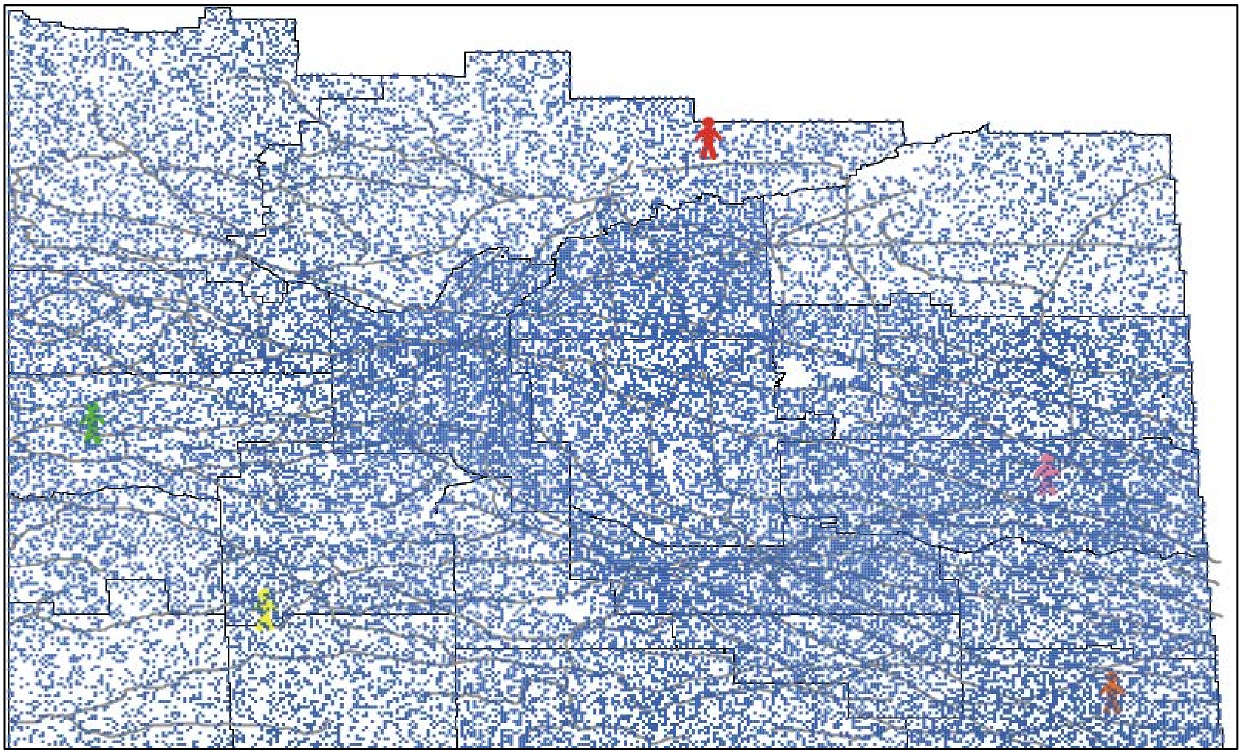

Figure 4.5: Random Farmer Agent Generation Based on Random Seed Algorithm: 100
Source: Created by author from *FARMCHAIN* model.

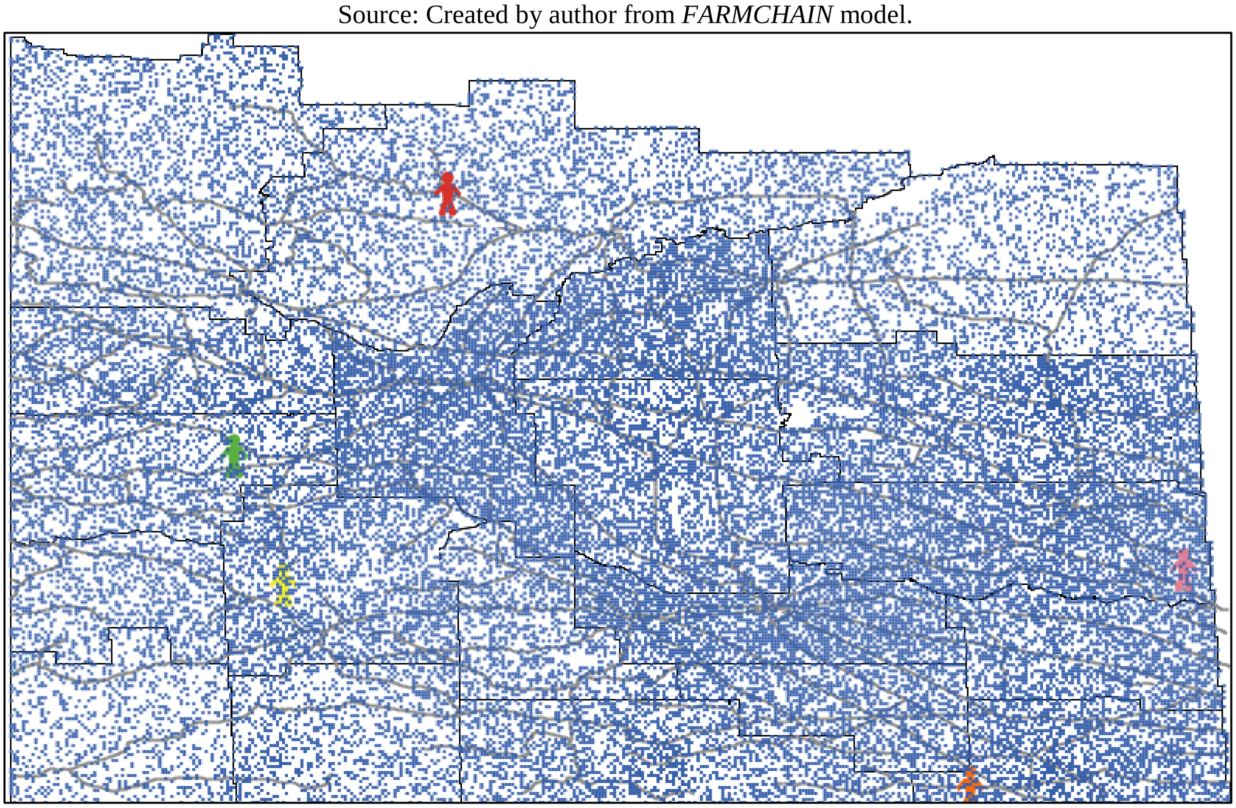

Figure 4.6: Random Farmer Agent Generation Based on Random Seed Algorithm: 98238
Source: Created by author from *FARMCHAIN* model.

4.2.4 Elevator and Processing Plants Locations

Grain elevators, ethanol plants, crushing plants and the biodiesel plant locations are based on approximate actual locations. A GIS shapefile is created based on the approximate location coordinates, obtained from Google Maps™ and geocoded into ArcMap©. Thereafter, the geodesic distances to port is computed externally and joined to the shapefiles.[18] The geographic locations of grain elevators (red houses), crushing plants (green houses), ethanol plants (yellow house) and the biodiesel plant (violet circle) is shown in Figure 4.7. The geodesic distance to port can be found in Table B-2 of Appendix B.

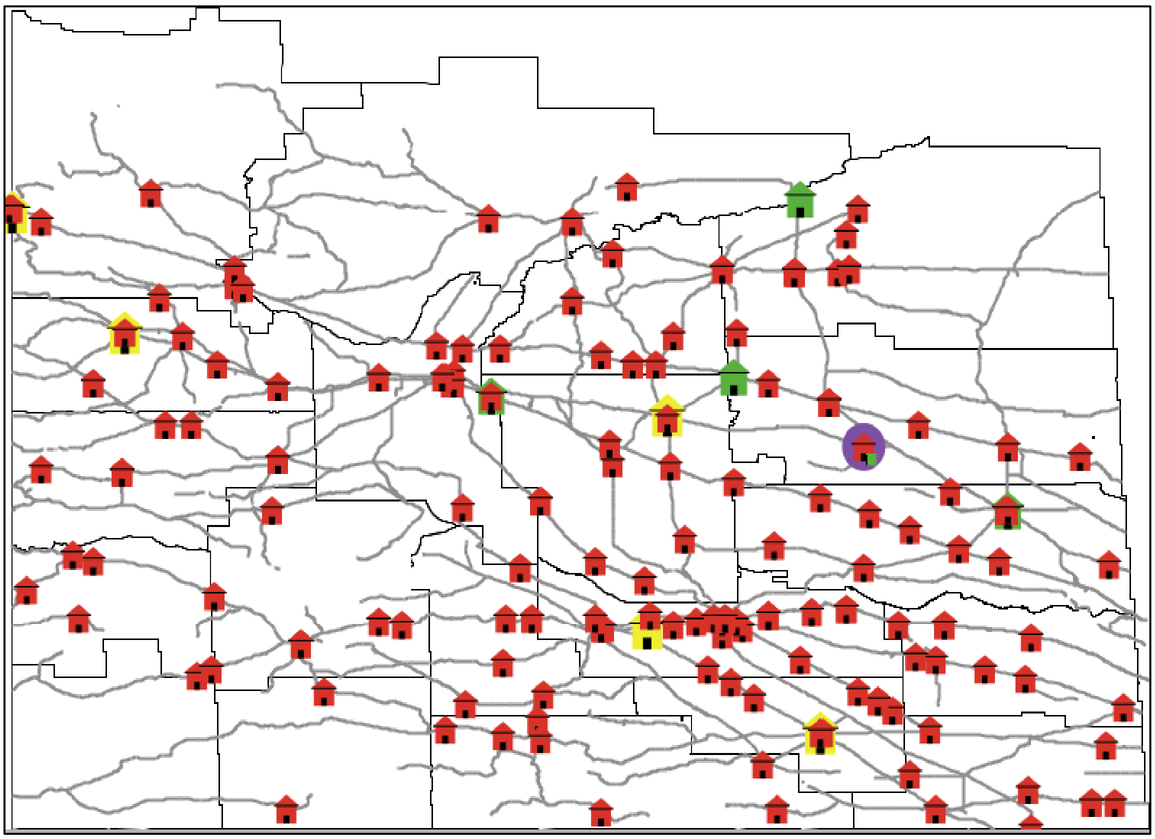

Figure 4.7: Locations of Elevators, Crushing Plants, Ethanol Plant and Biodiesel Plant in Saskatchewan
Source: Created by author.

4.3 Exogenous Crop Price Time Paths

World crop price paths are exogenously determined and stored in text files.[19] Due to the length of time it takes to complete a simulation, 50 time paths for each of the four crops (food wheat, canola, barley and field peas) is chosen.

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[18] Geodesic distances are computed using the formula at http://www.cpearson.com/excel/latlong.aspx given by:
$\mathrm{RadiusEarth} * ((2 * \mathrm{ASIN}(\mathrm{SQRT}((\mathrm{SIN}((\mathrm{RADIANS}(X1-\mathrm{coord}) - \mathrm{RADIANS}(X2-\mathrm{coord}))/2)\hat{}2) + \mathrm{COS}(\mathrm{RADIANS}(X1-\mathrm{coord})) * \mathrm{COS}(\mathrm{RADIANS}(X2-\mathrm{coord})) * (\mathrm{SIN}((\mathrm{RADIANS}(Y1-\mathrm{coord}) - \mathrm{RADIANS}(Y2-\mathrm{coord}))/2)\hat{}2)))))$, where Xi-coord is the i^{th} x-coordinate and Yi-coord is the i^{th} y-coordinate.

[19] Biofuel prices are determined endogenously and depend on crude oil prices.

4.3.1 Price Path Generation Process

Exogenous prices in Canadian dollars are based on de-trended prices and hence are adjusted for inflation and exchange rates. All world prices, with the exception of canola prices, are obtained from the UN Comtrade website (UN Comtrade, 2010). Price data from this website represent carriage in freight (CIF) prices (prices before ocean freight is deducted).[20] Real prices are displayed in Figure 4.8. More information on these prices can be found in Table B-3 of Appendix B.

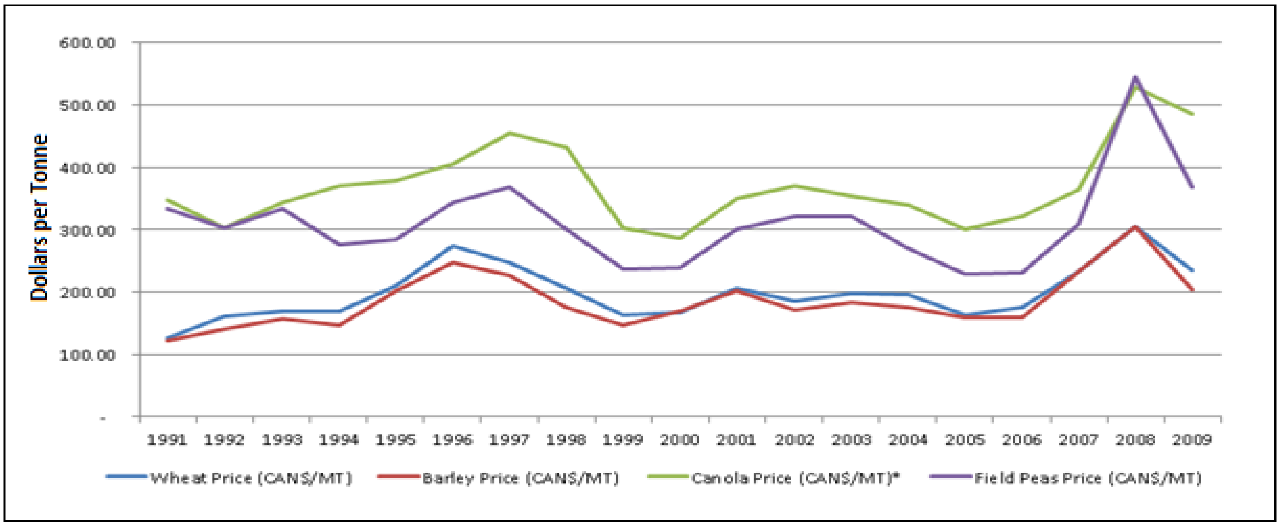

Figure 4.8: Detrended Real Annual World Prices for Wheat, Barley, Canola and Field Peas, 1991-2009.
Source: UN Comtrade, 2012; *Canola prices obtained from FAO STAT, 2012.

It is evident in Figure 2.7 that prices are contemporaneously related, and, in nominal terms, strongly upwards trending such that prices of all four crops increased significantly in 2008 and then markets corrected in 2009. After adjusting for inflation and differences in the US$:CAN$ exchange rate, prices are still very highly correlated (Table B-4). Price time paths are estimated using an autoregressive (AR) process for the adjusted prices, randomly resampling residuals to generate time paths. The inflation adjusted price data are fitted to AR(2) processes.[21] The regression results are shown in Table B-5. The residuals are stored for resampling in order to generate time paths for the model. Selected time paths had to meet three criteria: 1) no crop price

[20] CIF canola prices are not obtainable. FOB prices for canola are used as proxies CIF prices and are obtained from FAO-STAT website (FAO-STAT, 2012).

[21] The data are first tested for stationarity using Augmented Dickey-Fuller tests and are all stationary at the 5% level of significance.

should fall below $100 for any time period of the time path estimation; 2) the correlations between wheat and the three other crops should be within 20% of their historical correlations. Paths are generated for 15 time periods; and 3) the price space around the mean is adequately sampled. The 50 time paths generated for wheat, barley, canola and field peas appear to meet these criteria (Figures 4.9 through 4.12).

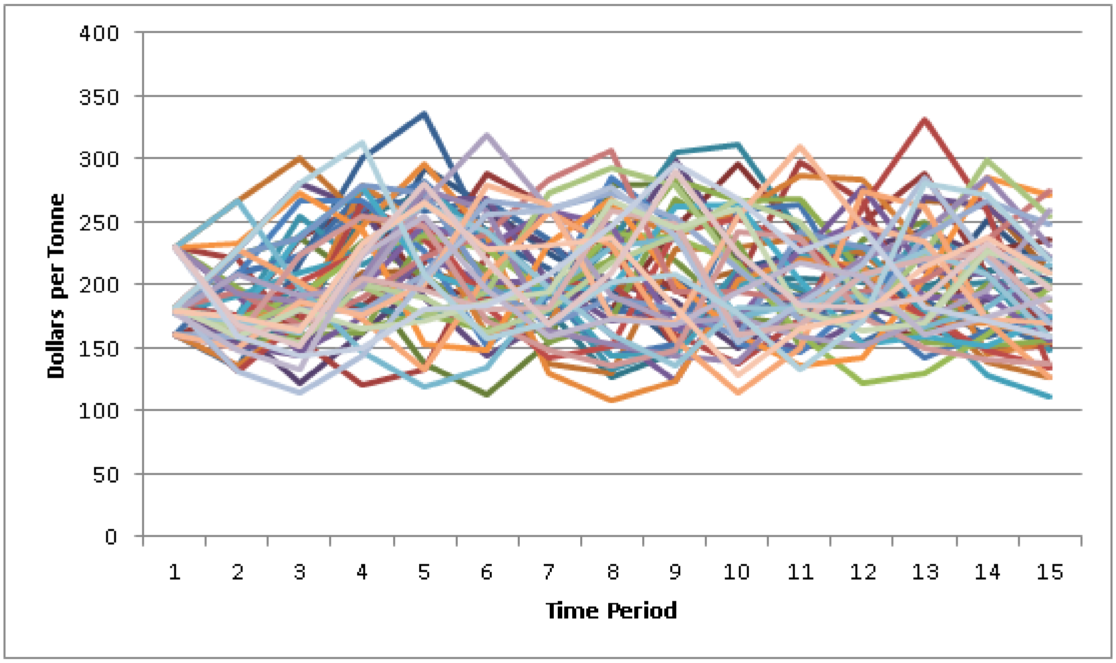

Figure 4.9: Projected Price Paths in Dollars per Tonne for Wheat for 15 Periods
Source: Created by author from author's calculations.

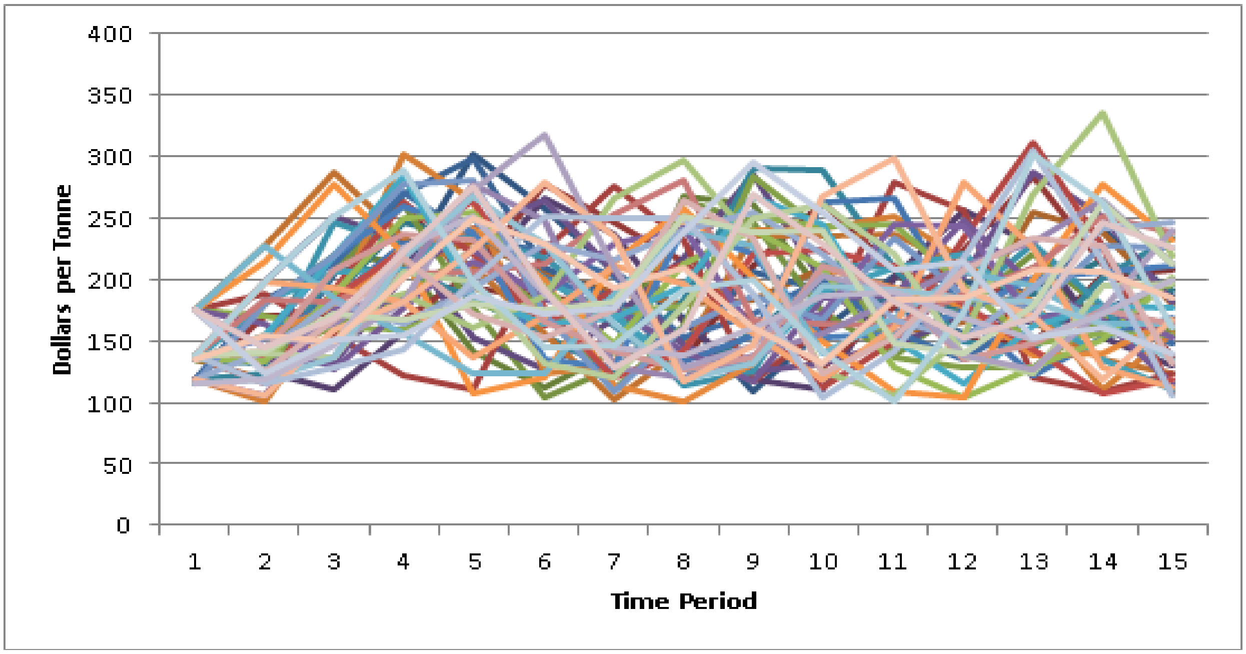

Figure 4.10: Projected Price Paths in Dollars per Tonne for Barley for 15 Periods
Source: Created by author from author's calculations.

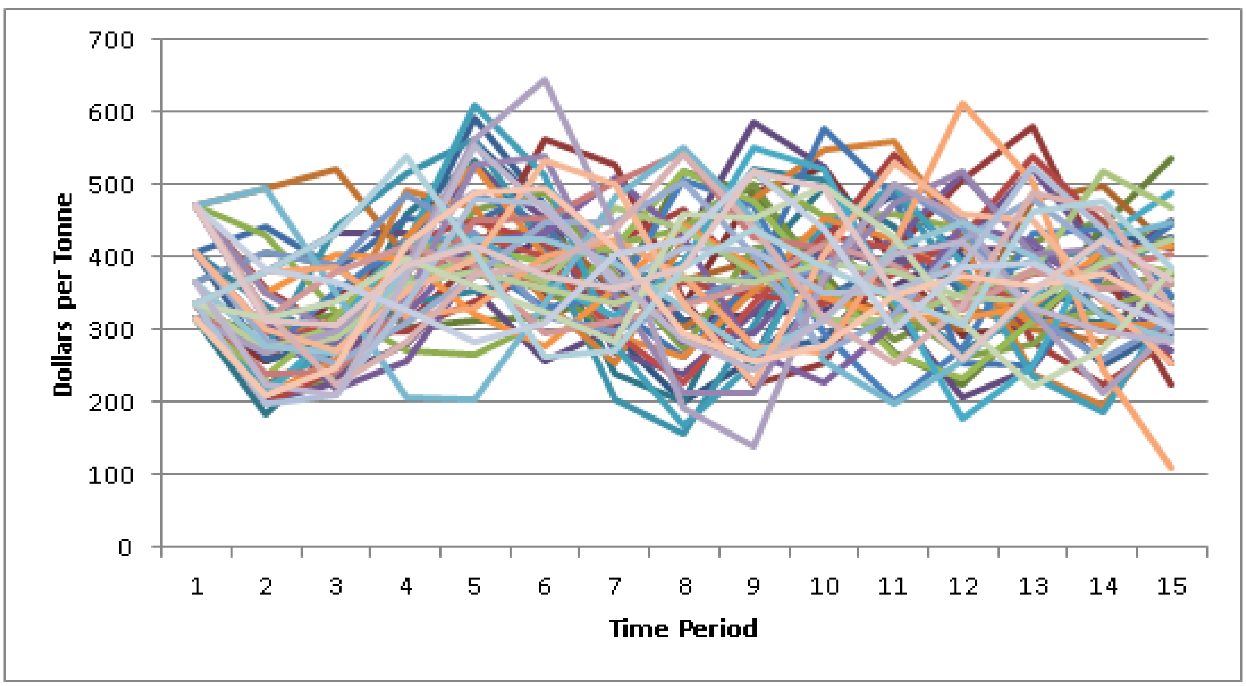

Figure 4.11: Projected Price Paths in Dollars per Tonne for Canola for 15 Periods
Source: Created by author from author's calculations.

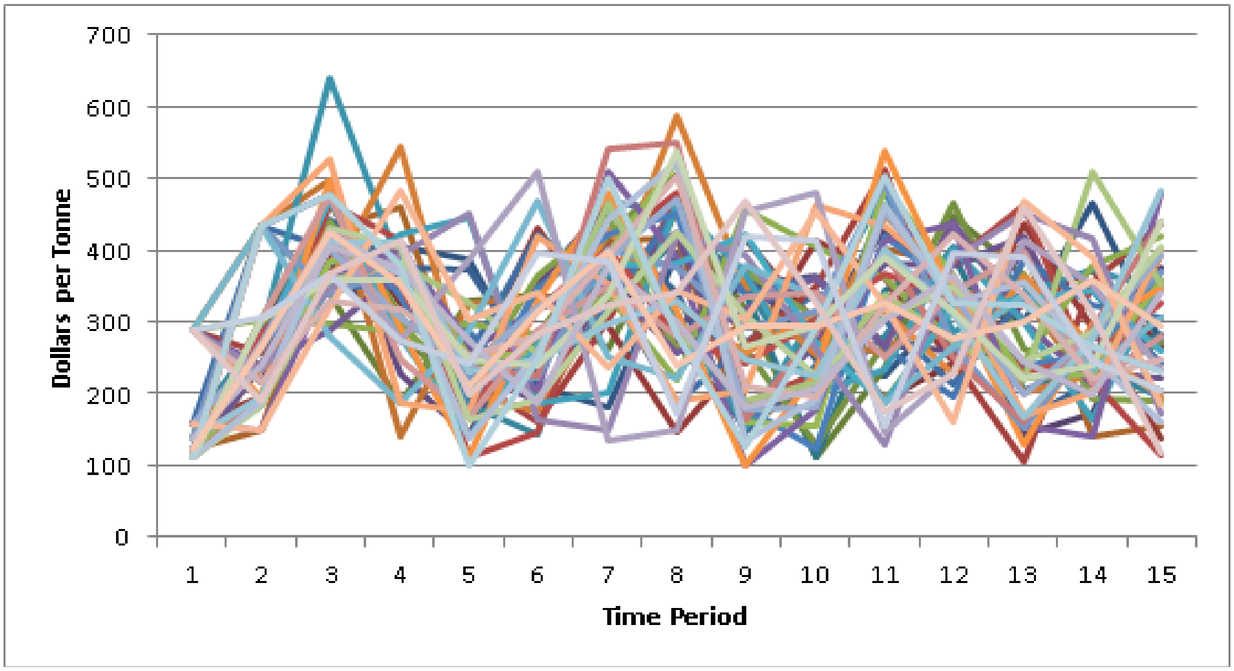

Figure 4.12: Projected Price Paths in Dollars per Tonne for Field Peas for 15 Periods
Source: Created by author from author's calculations.

4.3.2 Crude Oil Prices

Crude oil prices are endogenously determined and depend on the oil price scenario. In any scenario the real oil price is initialized at \$82.88 and reflects the real oil price at the beginning of 2010.

4.4 Farmer Agents

The following sections describe the data used to facilitate decision processes of the farmer. Continuing the discussion of Chapter 3, the proceeding sub-sections goes into greater detail highlighting the data used to parameterize equations. The discussion commences with farmer price expectations.

4.4.1 Price Expectations

The notion of weighted gross margins is proposed in Chapter 3. Recall equation (1):

$Expected\ Gross\ Margin_{t+1}^{j}$

$$= \left[(1-\varphi^n) \times Gross\ Margin_t^j + \varphi^n \times (World\ price_{t+1}^j - Variable\ Cost_t^j)\right] \times Yield^{j,l} \quad \dots (1)$$

The φ^n in equation (1) is exogenously generated following a uniformed distribution and randomly assigned to a farmer agent. Figure 4.13 shows the distribution of φ^n of farmers.

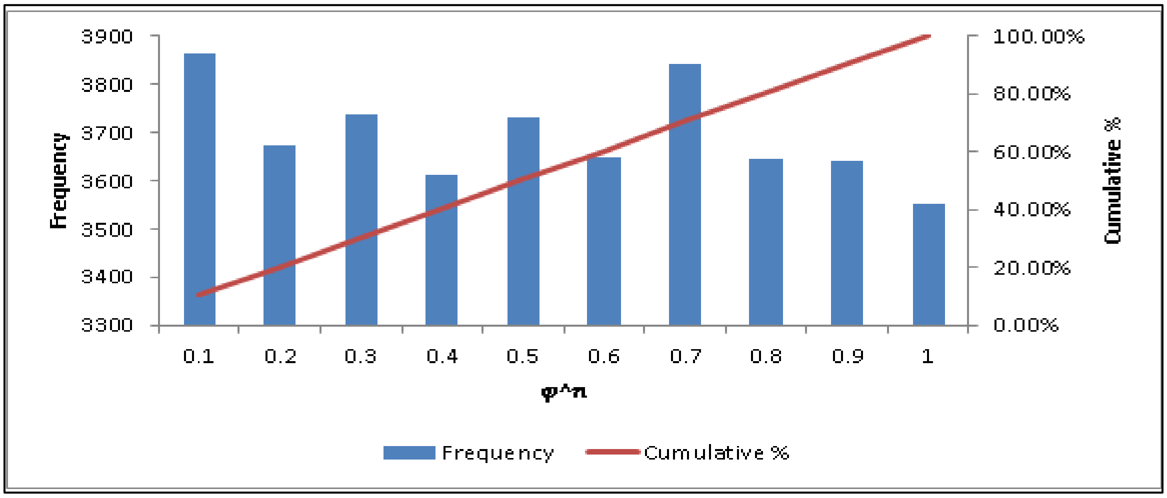

Figure 4.13: Distribution of φ^n of farmers.
Source: Created by author.

4.4.2 Farm Size

Farm size of the farmer agent is assumed to be randomly and uniformly allocated three standard deviations around the mean farm size of the CAR. The coefficient of variation in farm land sizes is assumed to be 25% for the 20 CARs. Total farm size used in the model represents a total crop land acreage which is less than a 1% deviation from of the sum of the actual wheat, canola, barley and field pea seeded acres in 2011. From Figure 4.14, it is evident that the distribution of the farm size of farmer agents is positively skewed with the mean land size of approximately 578 acres and the median land size of 546 acres. The maximum land size of farmer agents is 1,825 acres while the minimum land size is 71 acres.

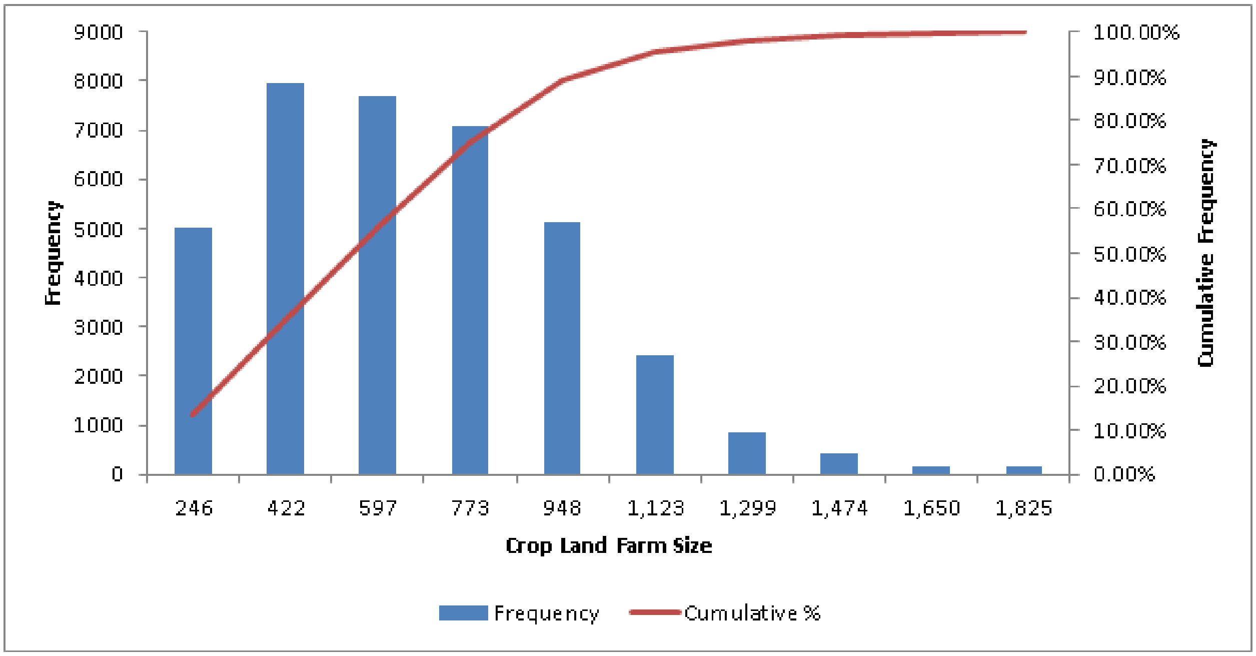

Figure 4.14: Distribution of Land Size of Farmer Agents.
Source: Created by author.

4.4.3 Land Allocation Packages

In Chapter 3 the basic feasible solutions to the famers' optimization problem were reduced to eight basic feasible solutions and could be iteratively tested to derive an optimal solution. A summary of the feasible solutions is presented Table 4.2. It reflects average allocation ratios across the 20 CARs. The coefficient of variation indicates the relative degree of dispersion around the mean. It is evident that the wheat-types would have received a land allocation between 35% and 48% of total land allocation on average, while canola would have been allotted allocation ratio between 18% and 32% of total land allocation on average. Barley and peas would compete at lower percentages. Therefore, barley, on average, is seeded on 16 to 22% of total land while peas are seeded on 12 to 18% of total land.

Table 4.2: Provincial Mean and Standard Deviation of Land Allocation Ratios, Saskatchewan

CROP	SW or (FW)	CAN	BAR	FP
BFS 1, (BFS 5)	0.48	0.18	0.22	0.12
	[0.14]	[0.52]	[0.16]	[0.66]
BFS 2, (BFS 6)	0.48	0.19	0.16	0.18
	[0.14]	[0.50]	[0.23]	[0.45]
BFS 3, (BFS 7)	0.35	0.31	0.22	0.12
	[0.29]	[0.40]	[0.17]	[1.22]
BFS 4, (BFS 8)	0.35	0.32	0.16	0.18
	[0.33]	[0.42]	[0.24]	[0.89]
BFS 5-8 represent FW allocations. In such a case SW = 0. The opposite is also true. Coefficients of variation are in brackets([]).				

Source: Computed from author's calculations.

4.4.4 Production Costs

At time $t = 0$ the unit production cost given by $TVC^{j,l}$ for the j^{th} crop in the l^{th} location is equal to the total variable costs outlined in Table 4.1 and depends on the location of the farmer on the landscape. Chacra (2002) and Baffes (2007) provide estimates of elasticities of changes in oil prices to changes in fuel prices and changes in oil prices to changes in fertilizer prices of 0.75 and 0.33, respectively.

4.4.5 Trucking Costs

A trucking cost schedule is obtained from Weyburn Inland Terminal website. An ordinary least squares regression is applied to the data to determine the functional relationship between trucking distance and the trucking cost per tonne. Table 4.3 shows the parameter estimates for the trucking function outlined in equation (4).

Table 4.3: Trucking Cost Parameter Estimates

Crop	Wheat	Barley	Canola	Field Peas
α	8.00 (0.0000***)	6.40 (0.0000***)	6.66 (0.0000***)	8.00 (0.0000***)
β	0.06 (0.0000***)	0.05 (0.0000***)	0.05 (0.0000***)	0.06 (0.0000***)
R-squared	0.997	0.997	0.997	0.997
P-values in parentheses.*** indicates statistical significance at the 1%level.				

Source: Weyburn Inland Terminal.

To compute the fuel surcharge elasticity, weekly percent surcharge and oil price data are obtained from the National Traffic Services (2012) and Energy Information Administration EIA (2011b), respectively. The data series are transformed by taking the logarithm. Both data series are tested for stationarity and are found to be integrated of order 1. The Johansen Cointegration test is administered and the trace test found that there is one cointegrating vector. Table B-6 in Appendix B shows the result of the cointegration test. The important thing to note is that the vector error correction model allowed for the estimation of the elasticity of changes in oil prices to changes in percent surcharge. According to the estimation $\varepsilon^{surcharge}$ in equation (9) is 1.04. This means that a 1% increase in oil prices would yield a 1.04% increase in the percent surcharge rate in the long-run. It is assumed in the *FARMCHAIN* model that the initial trucking surcharge rate is 10%.

4.5 Grain Elevators

Grain elevators are next in the *FARMCHAIN* supply network. Grain elevators receive crops trucked from farmers. A brief discussion of data used in determining storage and handling fees, crop disposition follows.

4.5.1 Storage and Handling Fees

Elevators handling and storage fees are assumed to be a function of the competitiveness within a predefined threshold. The six most prominent elevator companies in Saskatchewan are identified and tracked individually; all other elevators are treated as one group. Handling fees are assigned based on company and the level of competition within “close” proximity. The greater the levels of competition, the greater the likelihood that fees will be lower than the maximum fees. Table B-7 of Appendix B shows the maximum fees charged by an elevator company in 2010. Since the pricing behaviour of elevators is specifically unknown, fees are modified randomly assigned and are assumed to be based on the number of competitors in close proximity. For example, if an elevator (GE1) has three close competitors and, for a given period, the amount of wheat obtained from farmers is less that the average wheat receipts of all of the four elevators, then GE1 would reduce fees by an amount that is selected randomly choosing a integer between one and four (the number competitors plus GE1).

4.5.2 Crop Disposition

As noted in the previous chapter, a portion of crops delivered to elevators is forwarded to the port for export while the remainder disappears from the chain through domestic use. Utilizing 1996/97-2010/11 crop movement, approximately 43% of wheat production is forwarded to western ports. Over the same period, approximately 74% of field pea production is moved through western ports. In contrast, 19% of barley production is moved through western ports while 3% of barley production is moved through eastern ports (Table 4.4).

Table 4.4: *FARMCHAIN* Model Export Crop Disposition from Grain Elevators

Crop	West	East	Total Export Ratio
Wheat	42.9%	22.4%	65.3%
Barley	18.5%	2.5%	21.0%
Canola	89.0%	11.0%	100.0%
Field Peas	73.9%	0.6%	74.5%

[1/] Exports are apportioned based on Saskathewan's production levels relative to other Western Canadian Provinces and represent the ratio of export to total disposition of Canada.

Source: Computed by author with data from CGC Canadian Grain Exports 2010-2011 and CANSIM Table 001-0010.

Canola elevator deliveries are shipped through eastern or western ports. Although the total export ratio of canola was on average 55% of production over the period 1996/97-2010/11, it is assumed that canola leaving elevators is moved to the western and eastern ports at ratios of 89% and 11%, respectively. This only applies to elevators. With regards to crushing plants, it is assumed that canola crushing plants deliveries are transported via rail to either the ports or to the biodiesel plant. It is further assumed that 45% of crushing plant canola crop receipt is assumed to be forwarded to biodiesel plants, while 49% and 6% of canola crop receipts is assumed to be moved to the western and eastern ports, respectively.

4.6 Ethanol and Biodiesel Demand

Local trends in gasoline and diesel demand are estimated as a linear function of time. Figure 4.15 shows the trend in Saskatchewan retail gasoline and diesel sales over the period 1991-2011 and trend regression extrapolation for ten additional periods.

Therefore equations (13) and (16) of Chapter 3 can therefore be respectively parameterized as:

$$Dieseldemand_t(litres) = -113{,}470{,}246 \ + \ (57{,}559 * \ year)$$

$$gasdemand_t(litres) = \ -78{,}300{,}000 \ + \ (40{,}051 \times year)$$

Furthermore, the biodiesel blend requirement is 2% in Saskatchewan while the ethanol blend requirement is 7.5% as highlighted in Section 2.4. The conversion factors that convert tonnes of wheat to ethanol and tonnes of canola to biodiesel, ω^{eth} and ω^{BD}, are computed to be 371.75 and 1,083, respectively. These statistics were computed with data from GWA-DAF (2006) and FAPRI (2006) for ethanol and biodiesel, respectively.

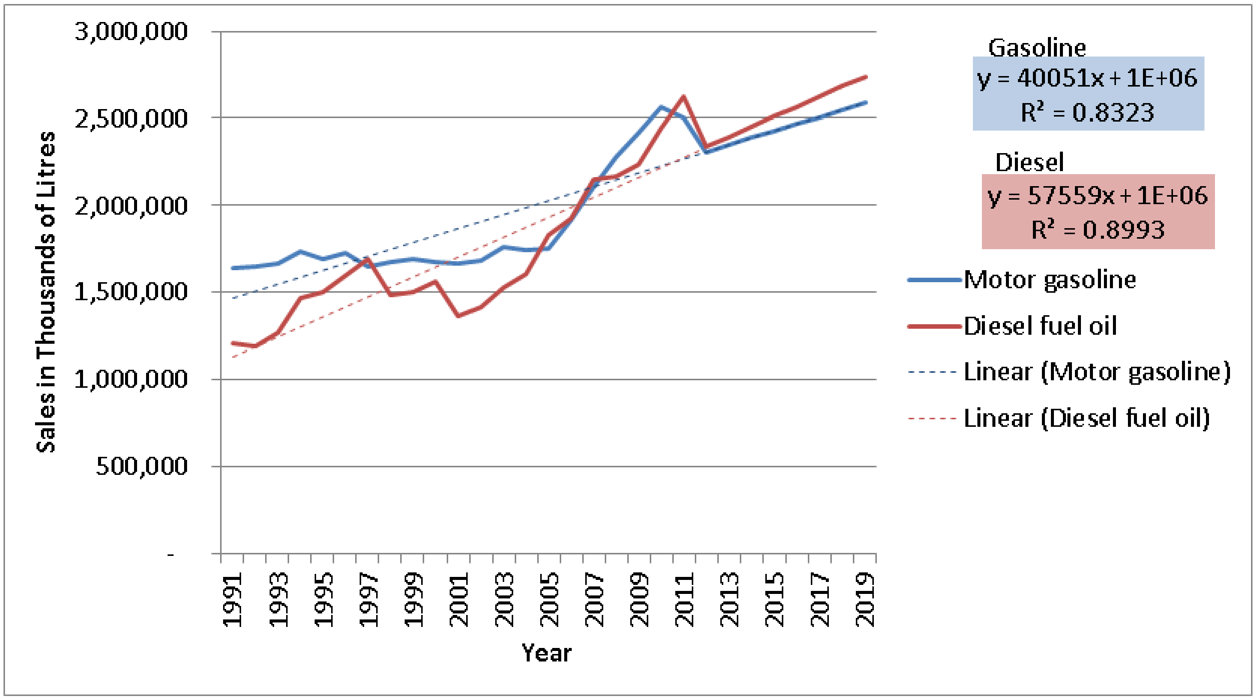

Figure 4.15: Trend in Actual and Projected Gasoline and Diesel Fuel Sales in Saskatchewan, 1991-2019
Source: Created by author with data compiled from CANSIM Table 326-0009

4.7 Rail Costs

Nolan and Carlson (2005) estimated the rail cost to be $0.02097 per tonne-mile. The adjustment factor, Adj_{factor}, of 2.2 is used to calibrate rail costs to be more reflective of estimates found in Canadian Grain Commission's Canadian Grain Exports 2010/11. In the case of biofuels, litres are converted to tonnes based on the following conversion factors:

- 1 litre of ethanol (ω^{Eth}) = 0.0007892 metric tons
- 1 litre of diesel (ω^{BD}) = 0.000885 metric tons[22]

4.8 Ocean Freight Costs

As highlighted in Chapter 3, in order for farmers to compute gross margins, they need to deduct ocean freight costs from the observed world price. The initial ocean freight rate of products leaving the west coast is assumed to be $26.38/tonne, the average of ocean freight rates from the North Pacific to Japan over the period August 2010 – December 2010 as reported in Canadian Grain Exports 2010/11. Using the same base and a relative price ratio of 70%, the initial freight rate from the St. Lawrence to South America is estimated at $19.67/tonne.[23] Furthermore, the parameter for the elasticity of ocean freight rates to changes in crude oil prices obtained from Hummels (2007), $\varepsilon^{freight}$ in equation (19), is 0.337.

4.9 Farmgate Price Determination

In order to obtain farm gate prices, data are needed to estimate ethanol and biodiesel prices. The following sub-sections describe how biofuel prices are determined. That is, the following sub-sections present the data used to estimate the relationship between biofuel prices and fossil fuel prices.

4.9.1 Ethanol Price Estimations

Following Tyner and Taheripour (2007), data are collected on oil prices and gasoline prices. Monthly oil prices (NRCAN, 2009) and monthly Saskatchewan retail gasoline prices (CANSIM

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[22] It is assumed that a litre of biodiesel weighs the same as diesel. Conversions for ethanol and biodiesel are obtained from Hazell (2013).

[23] The approximate distance from the Vancouver to Jakarta is over 13,000km while the distance to Tokyo is approximately 7,500km. The schedule of freight rates posted in the Canadian Grain Exports 2010/11 (CGC, 2011) indicate that freight rates from the Pacific Northwest to Japan is approximately 70% of that charged from the Pacific Northwest to Indonesia when the freight rate from the Pacific Northwest to Indonesia is $26.75. It is assumed that the approximate distance from the St. Lawrence to Venezuela, in South America, is 4500km and it is also assumed that freight rates can be apportioned by distance.

Table 326-0009) are adjusted for inflation. Gasoline prices are further adjusted downward for the 25¢/l federal and provincial government aid. This yields the pure price of gasoline.

The data series are then tested for stationarity using the Augmented Dickey-Fuller test. It is found that the data series are stationary after first differencing. Given that both series are integrated of order 1, I(1), the Johansen Cointegration test is administered (Table B-8 in Appendix B for results). It is found that there is one cointegrating vector implying a long-run linear relationship between oil prices and gasoline prices. The long-run component of the resulting vector error correction model (VECM) is used to parameterise equation (21). Table 4.5 shows the result of the cointegrating relationship of the VECM.

Table 4.5: VECM Gasoline Price on Oil Price Results

Coefficient	Coefficient Value	Standard Error	t-statistic
ρ^{gas}	42.23		
σ^{gas}	0.56	0.03	19.57

Source: Created from author's computation.

Therefore ρ^{gas} and σ^{gas} is estimated to be 42 and 0.56 respectively.
Tyner and Taheripour (2007) estimated that the fuel equivalent price of ethanol is 70% of the price of gas. Pimentel (2003) however noted that it would take 1.6 litres of ethanol to acquire the energy equivalent of a litre of gas. Therefore $\tau^{ethanol}$= 0.625.

It is assumed that energy related variable costs, $\omega^{ethanol}$= \$0.20/l and the initial ethanol margin, $ethanol\ margin_0$ = \$0.30/l, based on the study of ethanol production by the Government of Western Australia in 2006. In their study, energy related cost ranged from \$0.07 to \$0.09/l. The study also estimated that the non-feedstock variable cost of production was between \$0.13 and \$0.15/l. If these costs are reflected in 2010 prices they would closely approximate parameter values utilized.

There are considerable risks involved in operating a biofuel processing plant. It is assumed that entrepreneurship is rewarded by deducting a margin which is a percentage of sales. This margin is represented by π in equations (23) and (26) in Chapter 3. To be eligible for the federal government programs, returns must be less 20% (Pohit *et al.*, 2009). Since downside risk is significant in this industry, it is assumed that the margin will be close to 20%. Thus it is assumed that this rate is similar and constant across all ethanol plants and the biodiesel plant at 17.5%.

4.9.2 Biodiesel Price Estimations

The estimation approach for biodiesel prices is identical to that for ethanol. Oil prices (NRCAN, 2012) and retail diesel prices in Saskatchewan (CANSIM Table 326-0009) are adjusted for inflation. In order to give a pre-tax price, diesel fuel prices are further adjusted downward for the 39¢/l federal and provincial government aid.

The data series are then tested for stationarity using the Augmented Dickey-Fuller test. It is found that the data series are stationary after first differencing. Given that both series are integrated of order 1, I(1), the Johansen Cointegration test is administered (Table B-9 in Appendix B for results). It is found that there is one cointegrating vector implying a long-run linear relationship between oil prices and gasoline prices. The long-run component of the resulting vector error correction model (VECM) is used to parameterise equation (21). Table 4.6 shows the result of the cointegrating relationship of the VECM.

Table 4.6: VECM Diesel Price on Oil Price Results

Coefficient	Coefficient Value	Standard Error	t-statistic
ρ^{diesel}	33.14	1.48	22.38
σ^{diesel}	0.52	0.03	20.12

Source: Created from author's computation.

Therefore ρ^{diesel} and σ^{diesel} are estimated to be 33 and 0.52, respectively. Tyner and Taheripour (2007) estimated that the fuel equivalent price of ethanol is 90% of the price of gas. This means that $\tau^{ethanol}$= 0.9.

It is assumed that ω^{diesel}= 14¢/l and that the initial ethanol margin: $diesel\, margin_0 = 0.66$. These estimates are based on the 2009 estimates presented on the Ontario Ministry of

Agriculture Food and Rural Affairs (OMFRA) website, in which methanol cost estimates are \$0.13¢/l and the total operating cost excluding feedstock is \$0.40 ¢/l.

4.10 Summary

The parameter values and initial values of used in the FARMCHAIN model were discussed in this chapter. These values included production coefficients used to characterize the landscape and farmer productivity. Farmer heterogeneity was also delineated and its affect on production response is described. Parameters for crude price linkages to crop production, trucking costs, rail costs, ocean freight costs and biofuel production were highlighted. Initial values for the annual crude price as well as initial values for grain handling and canola processing were highlighted. These parameters and initial values are important for the generation of simulated data. The initial values outlined in this chapter are used paramtererize the FARMCHAIN model. The various commodity price time paths for the four crops (section 4.3) are the exogenous prices to the model and are held constant over the various energy price scenarios.

CHAPTER 5: VERIFICATION, VALIDATION AND RESULTS

5.1 Introduction

The two major objectives of this thesis are to 1) identify the real annual crude oil price that would entice farmer agents to switch from producing food wheat to producing biofuel wheat; and 2) to assess the impact of different government biofuel policies and increases in real crude oil prices on elevator behaviour. Through simulating the linkages between crude oil prices and Canadian prairie agriculture, these objectives are achieved by examining different scenarios with differing growth rates in real annual oil prices, levels of government support to the biofuel industry and levels of spatial competition between elevators. This chapter proceeds by outlining the verification process, followed by the base model's validation and results. Thereafter, counterfactual scenario results are presented for comparative purposes. Next, the impact of increased spatial competition between elevators is analyzed with respect to industry structure and performance. Finally, the chapter assesses the consequences of increasing oil prices and sustained biofuel polices on grain elevator pricing behaviour.

5.2 Model Verification

The *FARMCHAIN* model is verified at each stage of the model building process. Initially, the model landscape is verified by randomly selecting patches in the model, and comparing yield, production and cost coefficients with the tables created for the respective GIS shapefiles. Rules governing the processes of a farmer searching for an elevator, a farmer trucking his crop, an elevator identifying its competitors and all other decisions/computations are first coded in smaller models and verified for numerical accuracy in calculations as well as adherence to decision rules. After the codes are verified, they are incorporated into the larger model and are then re-verified using agents selected at random.

When the simulation model is complete, agents are then selected at random and variables under their control are then verified over successive time periods. Finally, a smaller scale but complete prototype model is run with agents' and global variables exported to Microsoft Excel© worksheets where they are once again verified and checked for validity.

5.3 Simulation Results

In total, eight scenarios are simulated using the *FARMCHAIN* model. Scenarios are differentiated by 1) the level of spatial competitiveness between elevators; 2) the growth rate in real crude oil prices and 3) the level of government support to the biofuel industry. Each scenario is simulated over fifteen time periods and fifty replications. The first four periods of each simulation are used to initialize the model, while in the fifth period the various scenario parameters are applied. The following discussion commences with the presentation of the results from the base model.

5.3.1 Base Scenario

The base model, labelled Scenario E0%-S25¢-R40km, represents current real world conditions and is used as a benchmark for comparison for the counterfactual scenarios. The base scenario incorporates actual 2010 elevator numbers and the current level of spatial competition level (P40km). In addition, government subsidies to the biofuel industry are sustained over the simulation period at: 25¢/l and 39¢/l in the ethanol and biodiesel industries, respectively. Finally, real annual crude prices are set at no annual growth (E0%).

5.3.1.1 Model Validation

Model validation refers to the comparison of model output results to reality or the assessment as to whether or not the simulation accurately represents what it is purported to depict (Gilbert, 2008). This model is validated based on four comparisons to real world data. This section discusses these comparisons.

5.3.1.1.1 Model Wheat Production versus Actual Historical Wheat Production

To begin this process, simulated wheat production is compared to actual historical Saskatchewan wheat production. Simulated total wheat production lies within the actual production range between 1999 and 2010. More specifically, an average of 8 million tonnes of wheat is produced in the *FARMCHAIN* model and this simulated amount is approximately 290 thousand tonnes greater than the actual mean wheat production over the period 1999-2010 (Table 5.1).

Table 5.1: Comparison of Simulated and Actual Historical Wheat Production (tonnes)

	Simulation Wheat Production	**Actual 1999-2010 Wheat Production**
Maximum	7,976,900	10,432,100
Minimum	7,888,583	4,545,000
Mean	7,943,063	7,655,300
Standard Deviation	31,939	1,468,301

Source: Constructed by author with data from the *FARMCHAIN* model, with data from Statistics Canada CANSIM Table 001-0010.

In a spatial context, food wheat production approximates actual three-year historical averages of spring wheat production. Census agricultural regions (CARs) 5 through 7 accounts for most of the spring wheat production while CARs to further north account for the least production (Table 5.2).

Table 5.2: Comparison of the Spatial Extent of Simulated Wheat Production to Historical Averages

Census Agricultural Regions	Actual Average Spring Wheat Production (2008-2010)	*FARMCHAIN* Model Simulated Mean Food Wheat Production
South (CARs 1-4)	2,395,337	2,042,197
Central (CARs 5-7)	3,087,806	3,219,775
North (CARs 8-9)	1,873,657	1,931,922

Source: Constructed by author with data from the *FARMCHAIN* model and with data from Saskatchewan Ministry of Agriculture (2012).

5.3.1.1.2 Simulated Ethanol Production versus Actual Ethanol Capacity

Ethanol production is compared to the existing production capacity of ethanol plants. It is expected that the simulated wheat production would not exceed actual ethanol capacity. However, the simulated mean ethanol production almost doubles the current ethanol capacity (Table 5.3).[24] This overestimation is due to the underlying assumptions of the model.

Table 5.3: Comparison of *FARMCHAIN* Simulated Ethanol Production and Actual Ethanol Production Capacity

FARMCHAIN Mean Ethanol Production (Litres)	Actual Saskatchewan Ethanol Production Capacity (Litres)	Percent Difference
623,314,183	342,000,000	82

Source: Constructed by author with data from the *FARMCHAIN* model and CFRA (2010).

[24] This difference between simulated ethanol production and actual ethanol capacity is primarily driven by the difference between simulated wheat for biofuel use and actual wheat for industrial use proportions.

It is assumed that ethanol production monotonically increases with feedstock. This implies that ethanol production is bounded only by the amount of wheat directed to the biofuel industry. It is also assumed that there are only two uses for wheat: wheat for biofuel or industrial purposes and wheat for food consumption. Therefore all wheat that is not consumed as food is used to produce bioethanol.

In actuality, wheat has other uses, which includes wheat used for animal feed. The relative proportions of non-food domestic wheat disposition in the model in comparison to historical average non-food domestic wheat disposition proportions are shown in Table 5.4. It is shown in the table that simulated biofuel wheat proportions in the *FARMCHAIN* model more accurately represent the total non-food disposition of wheat than for the industrial use disposition of wheat. This means that simulated estimates of biofuel wheat and ethanol production are conservative upper bound estimates of actual levels.

Table 5.4: Comparison of Simulated and Actual Domestic Wheat Disposition

Domestic Disposition/Production[1/]	Simulated Average (%)	1999-2010 Actual Average (%)
Industrial Use	19.7	1.1
Animal Feed and Dockage	0.0	15.1
Other Non-Food Domestic Disposition	0.0	4.2
Total	19.7	20.4

[1/]Domestic Disposition per unit of Production captures the non-food portion of wheat produced

Source: Constructed by author with data from the *FARMCHAIN* model and Statistic Canada Table 001-0041.

5.3.1.1.3 Estimated Mean Elevator Fees

Due to its importance to farmers' cropland allocation decision process, average initial food wheat elevator handling fee from the simulation is compared to those presented in Canadian Grain Exports reports (CGC, 2004; CGC, 2008; CGC, 2010; CGC, 2011). The mean elevator wheat handling fee generated by the model is \$1.64/t lower than the estimate provided by the Canadian Grain Commission over the crop years 2001/02-2010/11 (Table 5.5). This is largely due to the significant and uncharacteristic increase in mean primary elevating costs in the 2010/11 crop year to $24.48/t from $21.51/t the previous crop year. Nevertheless, the simulated mean is within 1 standard deviation from the mean estimates obtained from the Canadian Grain Commission's Canadian Grain Exports reports over the 11-year period.

Table 5.5: Simulated Mean Wheat Handling Fees Versus Estimates from Canadian Grain Exports Report over the Crop Years 2001/02-2010/11 ($/t)

Simulated Mean	CGC Estimates (2001/02-2010/11)					Difference between Means
	Minimum	Maximum	Mean	Median	Standard Deviation	
18.22	17.53	24.78	19.86	19.23	2.00	-1.64

Source: Constructed by author with data from the *FARMCHAIN* model and CGC (2004), CGC (2010), CGC (2011).

5.3.1.1.4 Cropping Patterns

This thesis primarily focuses on the impact of increased competition between food and biofuel wheat and therefore is less concerned with modeling other competing crops including canola, barley and field peas. Overall cropping patterns are chosen for validation because at a minimum, high level output patterns should remain somewhat consistent if we have developed a reasonable representation of the farming landscape. The mean simulated cropping pattern for all crops in the *FARMCHAIN* model is presented in Table 5.6. Given recent changes in the sector, the simulated seeded acres for canola underestimate the three-year average (2008-2010) but it overestimates barley and field pea allocations. The actual three-year average (2008-2010) allocation of canola, barley and field peas was 7.8 million acres, 3.1 million acres and 2.8 million acres, respectively (Saskatchewan Ministry of Agriculture, 2012), while in 2010 canola received the highest land allocation across the prairies (Saskatchewan Ministry of Agriculture, 2012). As different as the simulation and reality are in this respect, it is worth noting that canola still consistently received the highest land allocation in the model. Ultimately, the difference between the simulated and actual cropping pattern of canola generated here is due to the current high price of canola relative to wheat, a situation that has prompted farmers only recently to seed proportionately more canola than wheat. This means canola may continue to dominate the proportion of acres seeded in the province under the current price relationship, and that the simulated results are not an unreasonable representation of the reality.

Table 5.6: Simulated Mean Cropping Patterns, Base Scenario

Simulation Output Variable	Crop				
	Food Wheat	Biofuel Wheat	Canola	Barley	Field Peas
Mean Seeded Acres	5,503,026	1,500,046	7,740,945	3,567,357	3,055,317
Mean Seeded Acres Proportion (%)	25.76	7.02	36.23	16.70	14.30
Mean Yield (t/acre)	1.13	1.21	0.98	0.72	0.97

Source: Constructed by author with data from the *FARMCHAIN* model.

5.3.1.2 Base Scenario (E0% - S25¢ - R40km) Output Variable Performance Analysis

While a considerable number of output variables can be extracted from the model, four key simulated output variables are used to provide answers to the aforementioned research questions. These variables are: 1) total food wheat production, 2) total biofuel wheat production, 3) the mean number of elevators, and 4) the mean elevator wheat handling fees. Again, we note that the base scenario is characterized by relatively low spatial competition between elevators (R40km), combined with zero growth in real annual crude oil prices (E0%) and sustained government support to the biofuel industry (S25¢). Under this scenario, it is found that mean food wheat production fluctuates around 6.4 million tonnes while mean biofuel wheat yield equivalent production fluctuates around 1.6 million tonnes over periods 4 through 15 (see Figure 5.1). [25] Therefore a sustained biofuel support policy does not lead to any notable increases in biofuel wheat production.

The stability in wheat production is evident despite a significant decline in the number of elevators in the industry. In assuming a competitive pricing, elevators employ an undercutting pricing strategy in order to expand market share and mean fees decline as a result. Specifically, mean food wheat handling fees decline by 61.1% to $7.08/t over the simulation period. This price cutting strategy continues until the least competitive firms are forced to exit the industry. This is known as industry 'shakeout'. [26] The mean number of elevators declines by 70.5% to 52

[25] Yield equivalent biofuel wheat production means that biofuel wheat production is adjusted downward (dividing by a factor 1.07) to account for the fact that biofuel wheat yield is 1.07 times that of food wheat in the model. This allows for the direct comparison farm production terms of tonnes of wheat produced. From henceforth all subsequent references to biofuel wheat production are adjusted for yield equivalence.

[26] Industry "shake out" is defined here as a significant decline in the number of firms in an industry within a relatively short period of time (Horvath, Schivardi and Woywode, 2001)

over the simulation period (Figure 5.1). Although this decline is significant, it is not unreasonable as over the period 1999-2010 there was an actual decline of 61.9 per cent from 1035 in 1999. Such a decline would mean that on average, the throughput of an elevator would be approximately 136,000 tonnes of wheat in the last simulation period, approximately triple that of the initial period. Therefore, under the base scenario, when elevator firms employ a Bertrand pricing strategy there is industry consolidation and an increase in elevator capacity.[27] This finding is consistent with historical data as the prior consolidation of the industry led to firms investing in larger capacity plants (Storey, 2006).

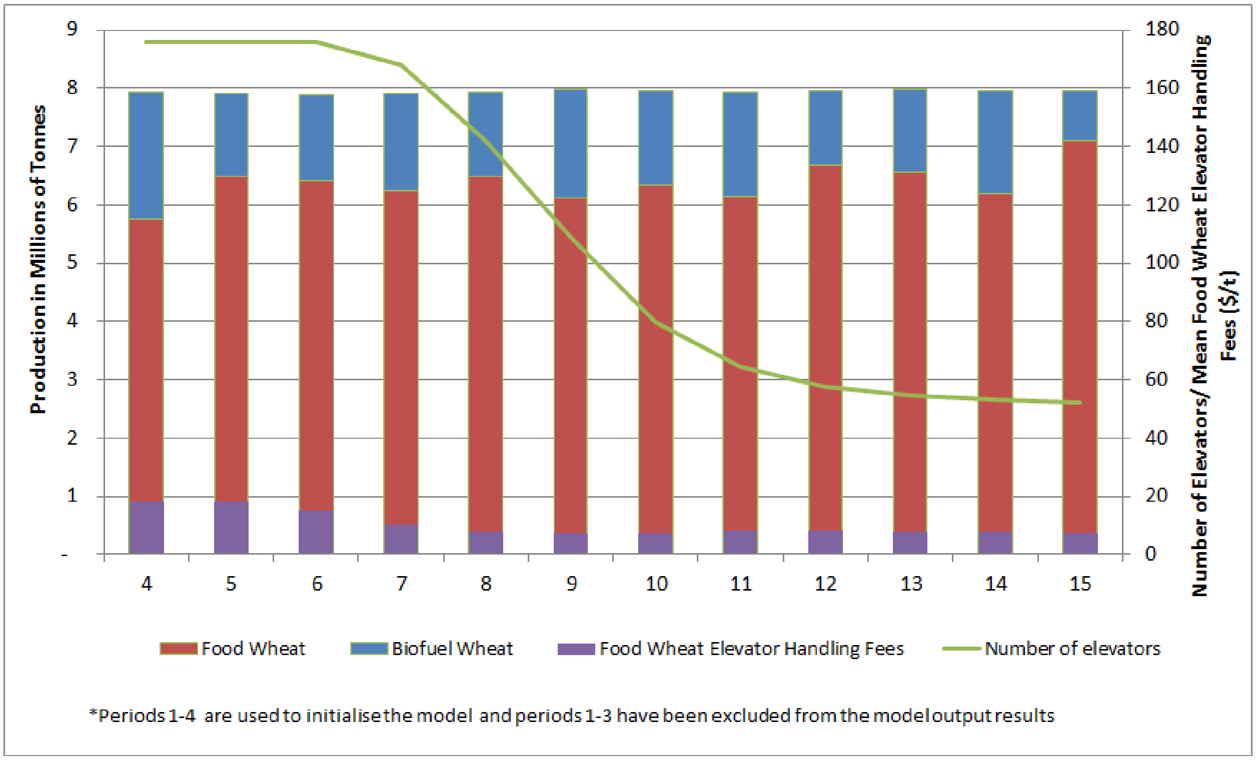

Figure 5.1: Simulated Mean Food Wheat Production, Biofuel Wheat Production, Food Wheat Handling Fees and Number of Elevators in the Base Scenario
Source: Created by author with data from the *FARMCHAIN* model.

Embedded in the revealed elevator consolidation, and driven by assumptions of the model, is the notion that elevator consolidation is brought about by spatial inefficiencies. It is assumed that marginal costs are zero for all elevator firms in the *FARMCHAIN* model. This assumption implies that any exit of elevators from the industry is totally attributable to spatial inefficiencies.

[27] Bertrand pricing strategy is the pricing strategy employed by firms in which the Nash equilibrium is the competitive equilibrium, that is, the equilibrium is marginal cost pricing. The outcome of such a strategy is that the inefficient firms are forced to exit the industry.

Initial prices set by elevators are lower with higher levels of rival competition. Also, higher levels of competition influence the degree of price change from one period to another. Therefore, a higher level of rival competition results in an accelerated decline in fees charged and a higher probability of insolvency. It therefore follows that elevator firms that are in locations that have a relatively higher density of elevators stand a greater chance of becoming insolvent. The initial spatial concentration of the elevators on the simulated landscape, based on actual 2010 geographical data (CGC, 2012), is shown in Figure 5.2. Here, the closer a patch in the simulation is to an elevator, on the landscape, the darker the shade of that patch.[28]

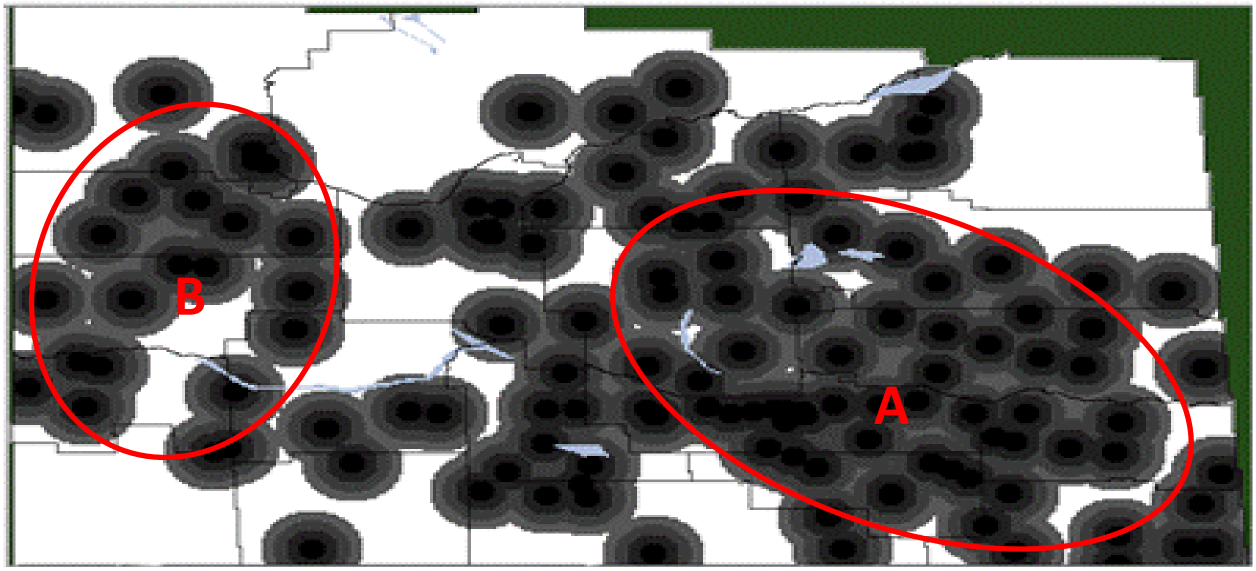

Figure 5.2: The Initial Spatial Concentration of Elevators on the Landscape
Source: Created by author with data from the *FARMCHAIN* model.

It is evident that from this Figure 5.2 that there is a large area of elevator concentration located in the eastern CARs (cluster or area A), with a minor area of concentration in the western part of the province (cluster or area B), while other much smaller pockets of elevator concentration exist in other parts of the province. As elevators compete spatially for wheat over the simulation period, the least competitive elevators are eventually forced to exit the market (Figure 5.3). The change in the spatial pattern of locations over the simulation indicates that elevators are effectively "surrounded" by other elevators are more susceptible to failure since they are less likely to be able to draw the same amount of grain as elevators on the periphery. In the simulation, these 'besieged' elevators are constantly forced to reduce handling fees in an effort to

[28] Blue Patches represents water masses and are excluded from the model analysis.

compete for wheat. As this process continues over time, these elevators are eventually forced to exit the market. Ultimately, this situation leads to what is termed a ‘donut’ shape of stable elevator location patterns, shown in Figure 5.3.

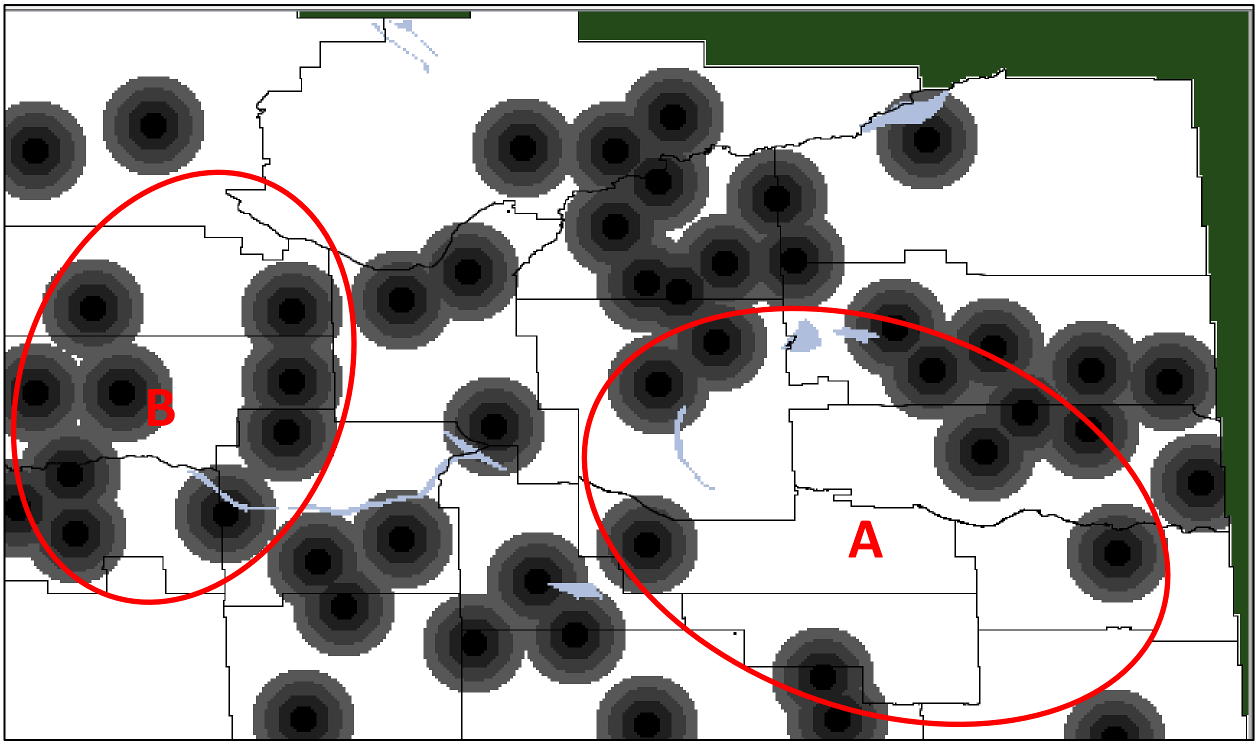

Figure 5.3: The Spatial Concentration of Elevators on the Landscape after 15 Periods
Source: Created by author with data from the *FARMCHAIN* model.

While somewhat emergent, this finding seems to accord with the prior notions of Lösch (1954) in the debate in the literature on location models (Hotelling, 1929; Lösch 1954). Specifically, Hotelling argued that, in the case of a duopoly, firms have a tendency to agglomerate. This assessment was countered by Lösch, who noted that the Hotelling outcome was only obtained under certain unrealistic conditions (see Appendix A). Lösch asserted that a location model accounting for the minimization of transportation costs of goods in the location decisions of firms would not lead to agglomeration, but to rather to firm dispersion in equilibrium. It is argued that the transition observed over simulated time from Figure 5.2 to Figure 5.3 supports Lösch’s supposition in that elevators surviving the industry shakeout are located farther apart from each other than when they started. In the *FARMCHAIN* model, this result is driven by the fact that interior wheat elevators necessarily have a reduced catchment area relative to those located on the periphery. Since the elevators compete using spatial Bertrand pricing (but measure performance of their strategy by observing relative quantities of deliveries or relative market share), elevators in the interior always reduce handling fees in an effort to compete and this process will force them to eventually shut down. As elevators begin to exit the market, those that remain are necessarily located farther apart with growing catchment areas by default.

5.3.1.3 Path dependency: Does Farmer Agent Location Assignment Matter?

Page (2006) defines path dependency as the effect often found in agent based modelling in which decisions made by agents in earlier time periods significantly affect future possibilities. Is this a potential issue with this situation? Due to the large number of farmer agents, it is suspected that location assignment will not affect results. In this section the possibility that initial farmer location assignments on the simulated landscape significantly affects the overall behaviour of agents as well as the model outcomes is examined. To assess whether the results from the base model are statistically different when the spatial assignment of farmer agents change, statistical tests of the difference between the simulated variable means are conducted based on two random seed algorithms used to generate farmer locations. The base scenario (scenario E0%-S25¢-R40km) under a random seed assignment of "100" and "98238" is compared. These results are shown in Table 5.6. It is revealed that altering farmer agent location in this manner does not yield statistically different model results at either the 1% or 5% level of significance.

Table 5.7: Statistical Test for the Difference between Means of *FARMCHAIN* Model Output Results

Item	Food Wheat Production	Biofuel Wheat Production	Elevator Food Wheat Handling Fees	Number of Elevators
(100)-(98238)[1/]	50742.79	-51417.77	0.55	0.61
Standard deviation	511244.70	549255.26	1.16	10.54
Test Statistic	0.10	-0.09	0.47	0.06
P-value	0.92	0.93	0.64	0.95

[1/](100)-(98238) represents the difference between means of the data of Scenario E0%-S25¢-R40km under random seed number 100 and random seed number 98238.

Source: Computed by author with data from the *FARMCHAIN* model.

5.3.2 Counterfactual Scenarios

The counterfactual scenarios are designed to test the sensitivity of wheat production, and elevator behaviour under current conditions (i.e. the base scenario) to increases in spatial competition, decreases in government support to the biofuel industry and increases in world crude oil prices.

More specifically, the counterfactual variables include: 1) a 40 km expansion of the competitive radius of grain elevators from the base to 80 km (R80 km), 2) a steady decline in government bioenergy support from 25¢ / l and 39¢ / l in the base ethanol and biodiesel support to and 18¢ / l and 19¢ / l (S18¢), respectively and 3) trend increases in energy prices of 10% per year (E10%) relative to no growth in the base scenario. All eight scenarios are summarised in Table 5.7.

Table 5.8: Summary of Scenarios

Scenario Number	Growth in Energy Prices (E)	Government Support to the Ethanol Industry[1/] (S)	Spatially Competitive Radius (R)	Scenario Reference Name
1 (Base)	0.0%	Sustained at 25 cents/Litre	40 km	E0%-S25¢-R40km
2	0.0%	Sustained at 25 cents/Litre	80 km	E0%-S25¢-R80km
3	0.0%	Decreases to 18 cents/Litre	40 km	E0%-S18¢-R40km
4	0.0%	Decreases to 18 cents/Litre	80 km	E0%-S18¢-R80km
5	10.0%	Sustained at 25 cents/Litre	40 km	E10%-S25¢-R40km
6	10.0%	Sustained at 25 cents/Litre	80 km	E10%-S25¢-R80km
7	10.0%	Decreases to 18 cents/Litre	40 km	E10%-S18¢-R40km
8	10.0%	Decreases to 18 cents/Litre	80 km	E10%-S18¢-R80km

[1/] For scenarios where government support to the ethanol industry is sustained at 25 cents per litre, government support to the bio-diesel industry is sustained at 39 cents per litre. For scenarios where government support to the ethanol industry declines to 18 cents per litre, government support to the bio-diesel industrydeclines to 19 cents per litre.

Source: Created by the author.

The counterfactual scenario results are presented and discussed in the following order of variable changes- 1) spatial competition; 2) declining government fuel subsidies and 3) increasing energy prices.

5.3.2.1 Base Energy Prices and Sustained Biofuel Support (S25¢)

Two levels of spatial competition, R40km (base) and R80km (high spatial competitiveness) are examined with the other two counterfactual variables set at their base values. Under the base level of elevator competiveness (R40km), no growth in world energy prices (E0%) and sustained biofuel support of 25¢/l (S25¢), food and biofuel wheat production under constant elevator fees is initially relatively close to current industry levels. This scenario is the base scenario that is presented in Section 5.3.1.2 and the key findings are reiterated here for comparative purposes to the higher level of spatial competition (P80km). In the base scenario, the pricing strategy which is assumed to be utilized by elevators results in decreased elevator fees. Over the simulated period, elevator handling fees decline by 61.1% by the end of period 15 from the initial level in period 4 (Figure 5.1).[29] These reduced handling fees lead to systematic elevator depopulation. For example, by period 15, the average number of elevators declines to 52 from 176 (Figure 5.1). Despite the significant change in the structure of the wheat handling industry, there is no significant change in the ratio of mean food wheat to total wheat produced over the simulation period. That is, food wheat production consistently accounted for approximately 80% of total wheat produced (Figure 5.1). This may be primarily due to the fact that the higher transportation cost of hauling grain further distances may be offset by reductions in elevator handling fees in latter periods of the simulation and does not entice farmers to change their choice of wheat crop allocation.

In comparison to the base level of spatial competition, increasing the competitive radius to 80km leads to a dramatically greater level of elevator competition primarily reflected in what is best characterized as a "roller coaster" of elevator fees. After three periods of initialization, and allowing a few more periods for agent behavior to change because of the lags associated with agent expectations, it is clear that handling fees in this case start to dramatically decrease in period 6 until they reach about 52.6% of the original fee by period 8 (Figure 5.4). Ultimately, this dramatic decline in handling fees leads to an industry 'shakeout' where most of the original 176 elevators are forced to exit the industry between periods 4 through 8, leaving just under 20 remaining elevators by the end of the simulation (Figure 5.4). The sharp decline in elevator fees shift the comparative attractiveness from biofuels wheat production back to food wheat slightly, stabilizing production briefly for periods 7 and 8 (Figure 5.5). Once this extreme "carnivorous" or cutthroat competition is finished, elevators then seem to shift to extracting more "rents" from the farmer agents with rapidly rising elevator fees: mean elevator fees increase over time to \$20.73/t by period 12 (Figure 5.4) before declining again as competition is rekindled, an effect in part due to reduced food wheat deliveries and increased biofuel deliveries (Figure 5.5). After period 12, there is a minor change in the number of elevator exits and mean elevator numbers decline to just 17 units at the end of the simulation period, a 67.5% decrease from the base

[29] The first four periods are used to initialize the model thereafter the counterfactual scenarios are imposed. Therefore the fourth period is used as an initial benchmark for each simulation period.

scenario. All of this is accompanied by a reduction in mean handling fees at the end of period 15 to \$16.15/t (Figure 5.4), \$1.31 above period 4 handling fees and 1.3 times the base scenario.

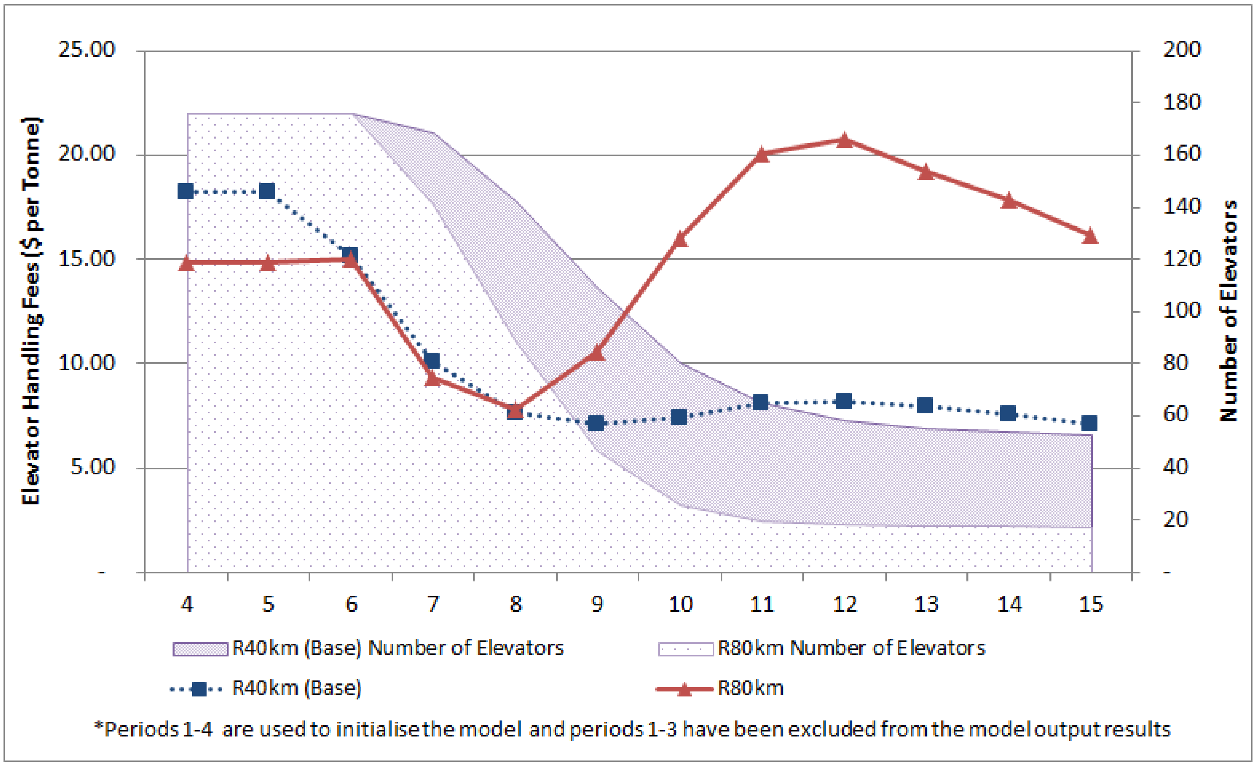

Figure 5.4: Simulated Mean Elevator Wheat Handling Fees and the Number of Elevators- Base Energy Prices and Biofuel Support (E0%-S25¢-R40km and E0%-S25¢-R80km)
Source: Created by author with data from the *FARMCHAIN* model.

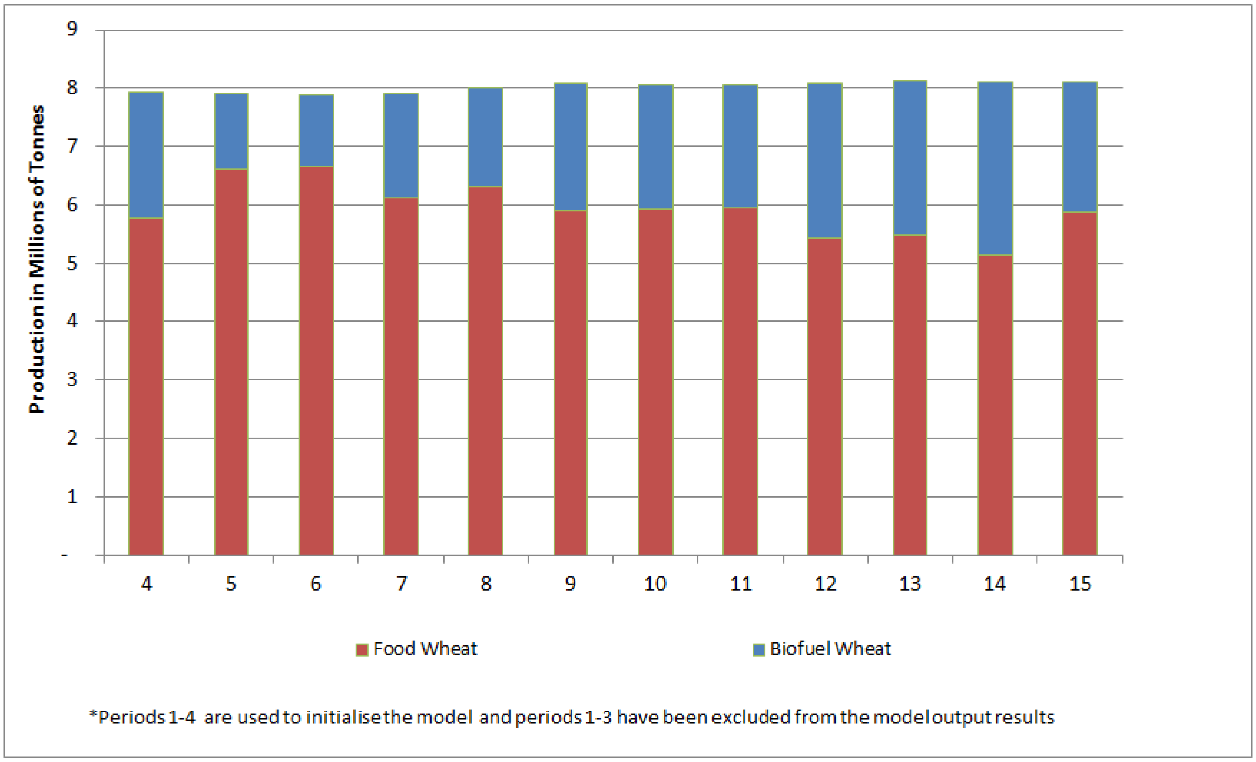

Figure 5.5: Simulated Food Wheat and Biofuel Wheat Production under High Spatial Competition, Base Energy Prices and Biofuel Support (E0%-S25¢-P80km)
Source: Created by author with data from the *FARMCHAIN* model.

5.3.2.2 Base Energy Prices and Declining Biofuel Support (S18¢)

Using the base 40km radius of spatial elevator competition and assuming declining biofuel support but with no growth in crude prices, food (biofuel) wheat production increases (declines) by 31.9% (81.6%) over the simulation period (Figure 5.6). This is due primarily to the decline in government support to the biofuel industry. As support diminishes the price that ethanol producers can offer feedstock producers is relatively lower than food wheat prices. Therefore, on average, the net return to seeding biofuel wheat would be less than that of food wheat.

This dramatic shift from bioenergy to food wheat production is further exacerbated by a decline in handling fees emanating from the Bertrand price competition. Specifically, handling fees decline from $18.22 in period 4 to $7.33/t (2.4% above the base) in period 9 and increase slightly to $9.32/t (31.7% above the base) in period 15 (Figure 5.7). The smaller overall decline relative the base scenario is driven primarily by the reduced competition for wheat deliveries from the bioenergy sector in the latter periods of the simulation. That is, there are endogenous effects generated from declining government support to the biofuel industry; as support declines, ethanol plants price less competitively and are therefore unable to attract as many producers. As a result, there are increased elevator deliveries and hence, elevators observing this, are able to extract more rents from producers by charging higher handling fees.

The reduced inter-industry competition results in a marginally milder industry shakeout when compared to the base. In other words, the reduced competition for producers' wheat increases the probability of solvency of elevators. More specifically, from the simulation it is found that there are, on average, 54 elevators solvent at the end of period 15, 69.2% below the initial number of 176 but 3.8% over the base scenario (Figure 5.7).

Increasing the level of spatial competition to 80km results in a similar wheat production phenomenon as is found in the base scenario in which the dynamics of spatial competitiveness neutralizes the effect of decreasing government support to the biofuel industry, yielding relatively stable food wheat and biofuel wheat production. The increased competitive radius initially generates extreme or cutthroat competition which depresses elevator fees to \$8.13/t by period 8, (Figure 5.7). Concurrently, the reduced handling fees charged lead to a 50.1% exodus of the initial 176 elevators from the industry by the end of period 8. After the industry 'shakeout' has occurred, intra-industry competition significantly decreases and so does the rate of elevator insolvency. That is, by the end of period 12 the elevators have stopped exiting the industry and by the end of the simulation period there are 18 elevators in operation (Figure 5.7). The reduction in competition after period 8 allows solvent elevators extract increased rents from producers and as such there is a significant in recovery in elevator fees to \$21.37/t by period 15 (Figure 5.7).

The decrease in government support from 25 to 18¢/l makes the cropping of food wheat more attractive to producers. However, with response lags of producers and the increased intensity of competition which leads to a significant adjustment in the number of elevators very early in the simulation (that in turn led to significantly higher fees), the growth in food wheat production found under low competition is not particularly evident in the higher level of spatial competition. That is, food (biofuel) wheat production is relatively static at 6.5 (1.5) million tonnes. This means that average food (biofuel) wheat production under high competition is 6.7% (53.8%)

lower (higher) than food (biofuel) wheat production under low competition. Relative to the base scenario, the impacts of declining government support and increasing competition result in marginal increases of 0.9% and 1.3% in both average biofuel and food wheat production, respectively. This implies that wheat, as a result, is marginally more competitive relative to canola in this scenario than in the base scenario.[30] Total wheat production in this scenario exceeds 8 million tonnes in each period after the industry 'shakeout' in period 8 (Figure 5.6) while in the base wheat production is below 8 million tonnes for the entire simulation (Figure 5.1).

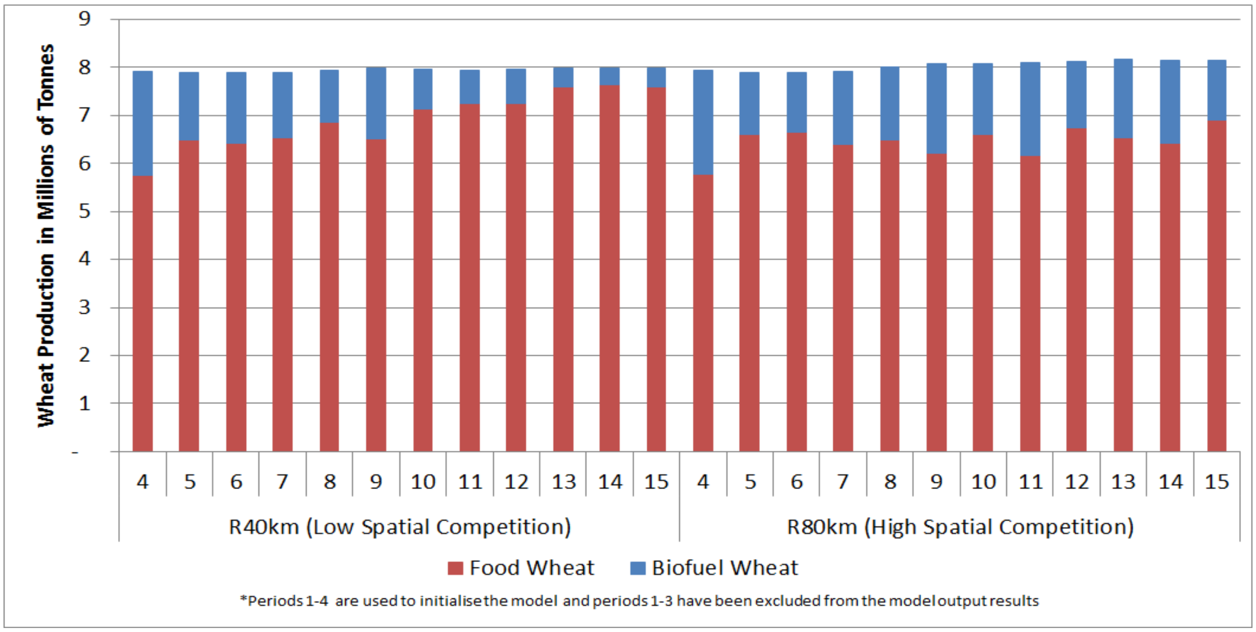

Figure 5.6: Simulated Mean Food Wheat and Biofuel Wheat Production- Declining Biofuel Support and Base Energy Prices (E0%-S18¢-R40km and E0%-S18¢-R80km)
Source: Created by author with data from the *FARMCHAIN* model.

[30] Since yields do not change over time, the only way to increase production is to increase land allocation. Recall in Chapters 3 and 4 that wheat competes with canola therefore expansion of wheat acreages arise primarily at the expense of canola acreages.

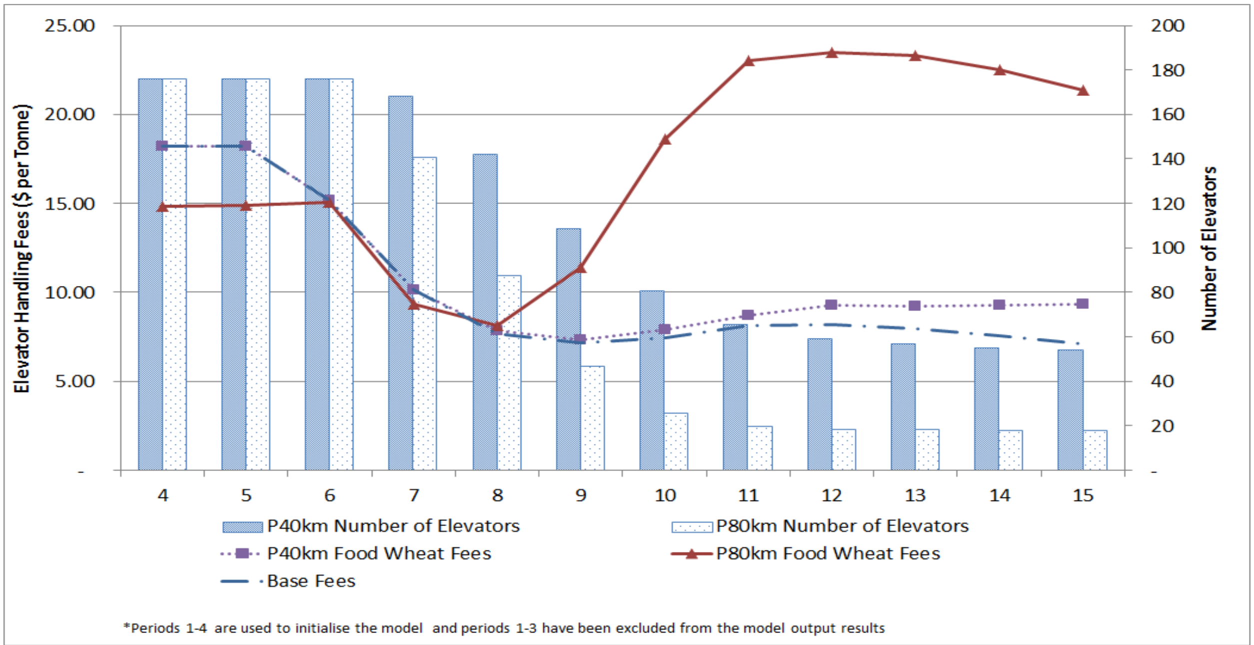

Figure 5.7: Simulated Mean Elevator Handling Fees and Number of Elevators- Declining Biofuel Support and Base Energy Prices (E0%-S18¢-R40km and E0%-S18¢-R80km)
Source: Created by author with data from the *FARMCHAIN* model.

5.3.2.3 Ten Percent Growth in Real Annual Crude Oil Prices (E10%)

The final set of scenarios in the simulation are founded upon a 10% annual increase in real crude oil prices, along with the two levels of government support to the biofuel industry and two levels of spatial competition. Note that a sustained 10% annual increase in real crude oil prices over the duration of the simulation is very aggressive, and with compounding results in a 318% increase over 15 years. This has a profound impact on not only the value of bioproducts but also on farm operating and transport costs.

5.3.2.2.1 Sustained Biofuel Support (S25¢)

The direct economic effect of higher energy prices is so overwhelming that spatial competition and government support have little overall impact on the simulated mean food wheat production. Food wheat production decreases substantially while simulated mean biofuel wheat production increases over the simulation period (Figure 5.8). This is driven by the idea that increases in fuel prices increase both food wheat transportation and production costs thereby reducing the competitiveness of food wheat. On the other hand, increases in fuel prices make the cropping of biofuel wheat more attractive and indirectly makes food wheat less competitive. In particular, when compared to initial levels of spatial competition at the end of period 4, average simulated food (biofuel) wheat production steadily decreases (increases) by 89% (240%) to 619,000 tonnes (7.3 million tonnes) by the end of period 15. Additionally, on between periods 9 and 10, biofuel wheat production surpasses food wheat production, with the estimated price of crude being between$133.48 /barrel and $146.83/ barrel (Figure 5.8). Placed in context, given that the annual price of crude in 2008 was $104 (the highest on record), prices would have had to be at least 28% higher than they were in 2008 to entice a majority of the farmers to switch to biofuel wheat production.

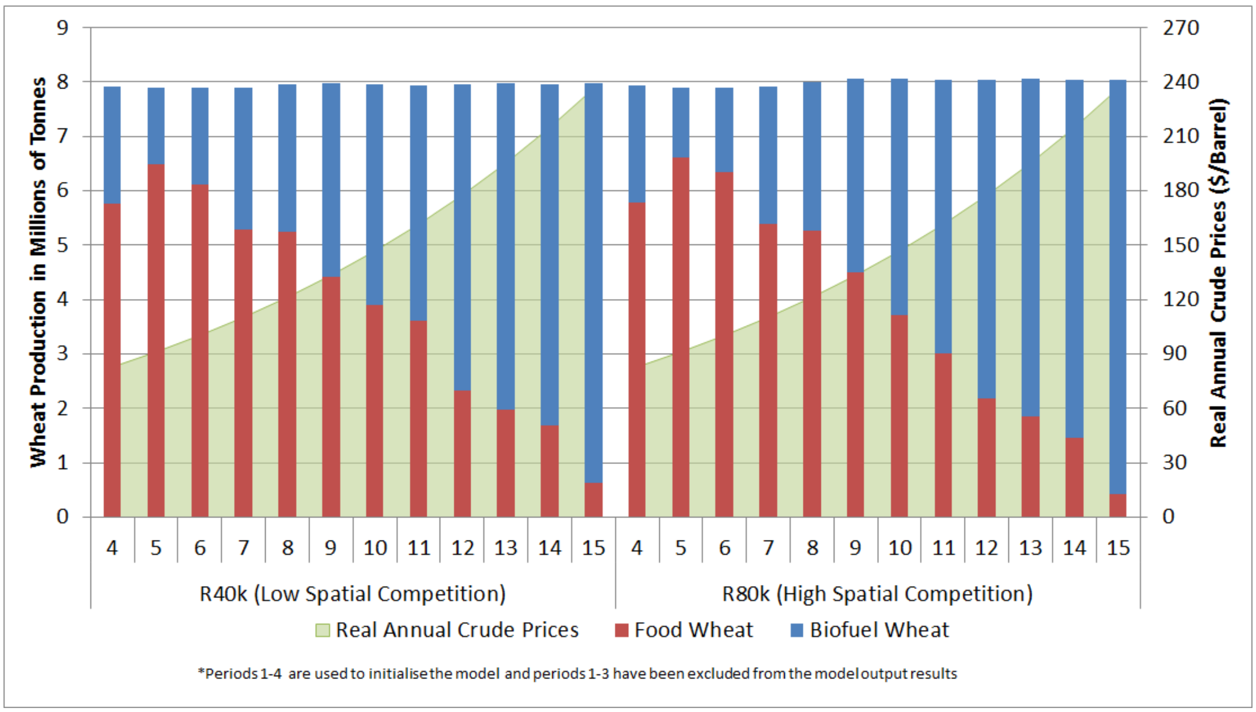

Figure 5.8: Simulated Food Wheat and Biofuel Wheat Production- 10 Percent Growth in Energy Prices and Sustained Biofuel Support (E10%-S25¢-R40km and E10%-S25¢-R80km).
Source: Created by author with data from the *FARMCHAIN* model.

The patterns of grain elevator competition as measured by mean handling fees charged and elevator numbers (Figure 5.9) are generally consistent with the results shown in Section 5.3.2.1, except that instead of stabilization in handling fees at period 11, there is a significant decline in fees. It appears that after period 11, changes in handling fees are as a result of crop competition and not due to spatial competition. Since at that period of time biofuel production is more attractive to farmers, elevators continue to lower fees in order to compete for the declining food wheat supplies. In particular, under low spatial competition (R40km), elevator fees continues its decline in period 12 and by period 15, declines to a remarkable low of $1.09/t (84.6% below the base) as is displayed in Figure 5.9. The average number of elevators in this case declines to approximately 50 (4.1% below the base) from 176 over the simulation period (Figure 5.9).

A high level of spatial competition (R80km) results in similar dynamics as is presented in the lower level of spatial competition (R40km). Increasing the level of spatial competition increases the elasticity of food wheat production to increases in biofuel wheat prices from 3.5 to 4.0 in absolute terms. Specifically, under high competition, food wheat production significantly declines by 92.7% to 420 000 tonnes (94.1% below the base) over the simulation. The increased sensitivity brought about by the increased competition is primarily driven by elevator responses to the changing industry conditions.

A similar industry shakeout is observed, with handling fees falling to $7.63/t (60.9% below the base) as of period 8, resulting in falling elevator numbers but a return of fees to $15.00/t before declining again to $4.29/t. However, the disruptive nature of the greatly diminished wheat supply prevents spatial elevator monopsonies from forming as competition intensifies again driving elevator fees down to 69.2% of base prices at the end of period 15. The impact of this destructive competition is such that at the end of period 15, elevator numbers decline from 176 units to approximately 16 units, the fewest of any of the simulated scenarios (Figure 5.9). The overall higher fees charged under increased spatial competition relative to low spatial competition reduces the relative competitiveness of food wheat production to biofuel wheat production. This has in turn led 32.1% lower food wheat production under high spatial competition relative to low spatial competition at the end of period 15 (Figure 5.8).

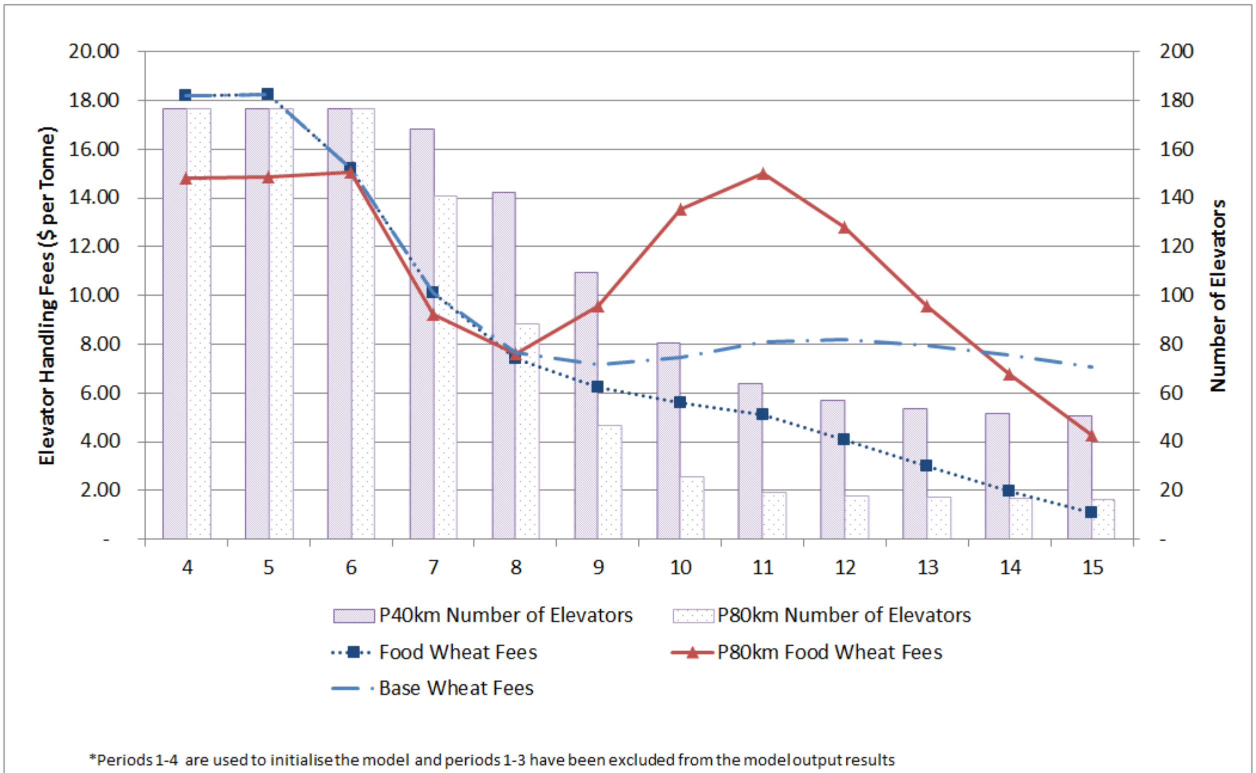

Figure 5.9: Simulated Mean Elevator Wheat Handling Fees and the Number of Elevators- 10 Percent Growth in Crude Oil Prices and Sustained Biofuel Support (E10%-S25¢-R40km and E10%-S25¢-R80km).
Source: Created by author with data from the *FARMCHAIN* model.

5.3.2.2.2 Declining Biofuel Support (S18¢)

In the last scenarios, declining industry support for biofuels is combined with strong growth in energy prices at the aforementioned 10% per year. Using the base level of competition (P40km), the former strong shift from food to bioenergy wheat by farmers is slightly moderated as compared to the previous scenarios: in this case, biofuel wheat production surpasses food wheat production later in the simulation, and at approximately $178 / barrel oil price (Figure 5.10) with final food wheat production at only 1.4 million tonnes (80% below the base) (Figure 5.10). The mean handling fees decline from $18.22/t to $1.81/t (or 74.5% below the base) in the last period (Figure 5.11). In turn, the average number of elevators declines from 176 to approximately 50 units (69% below the base) by the end of period 15 (Figure 5.11).

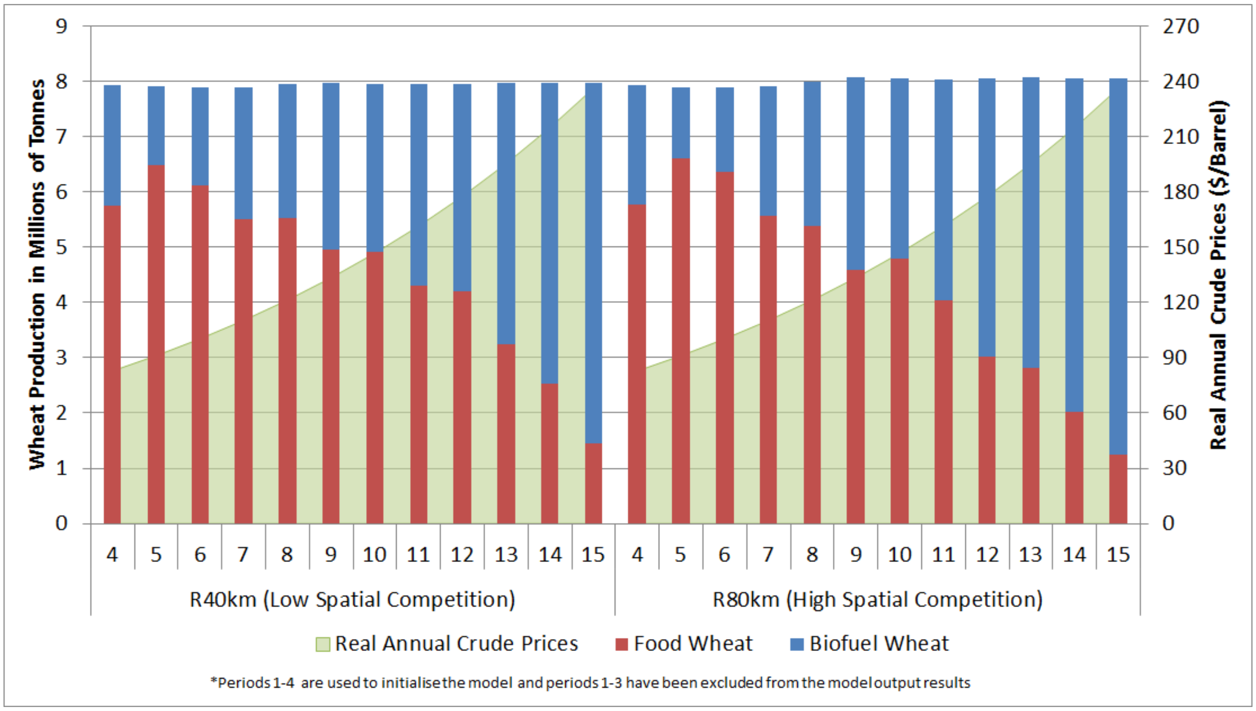

Figure 5.10: Simulated Food Wheat and Biofuel Wheat Production- 10% Growth in Crude Oil Prices and Declining Biofuel Support (E10%-S18¢-R40km and E10%-S18¢-R80km).
Source: Created by author with data from the *FARMCHAIN* model.

Under greater levels of spatial competition, simulated average food/bioenergy wheat production is slightly higher/lower than the previous scenarios with sustained biofuel support, reflecting the effect of lower spatial competition (Figure 5.10). Mean biofuel wheat production surpasses food wheat production in period 11 in this case, with a corresponding crude price per barrel of approximately $162 (Figure 5.10). While the general time path of fee charges and elevator numbers follow that of the like scenario with lower competition, the loss of cropland allocation from food to bioenergy wheat generated from relatively lower wheat competition and the associated higher levels of grain competition allows elevator fees to remain somewhat higher in the later years at $6.36/t, or 2.5 times higher at the end of period 15 (Figure 5.11). The mean number of elevators in this scenario is also slightly higher than before at 17 units (Figure 5.11).

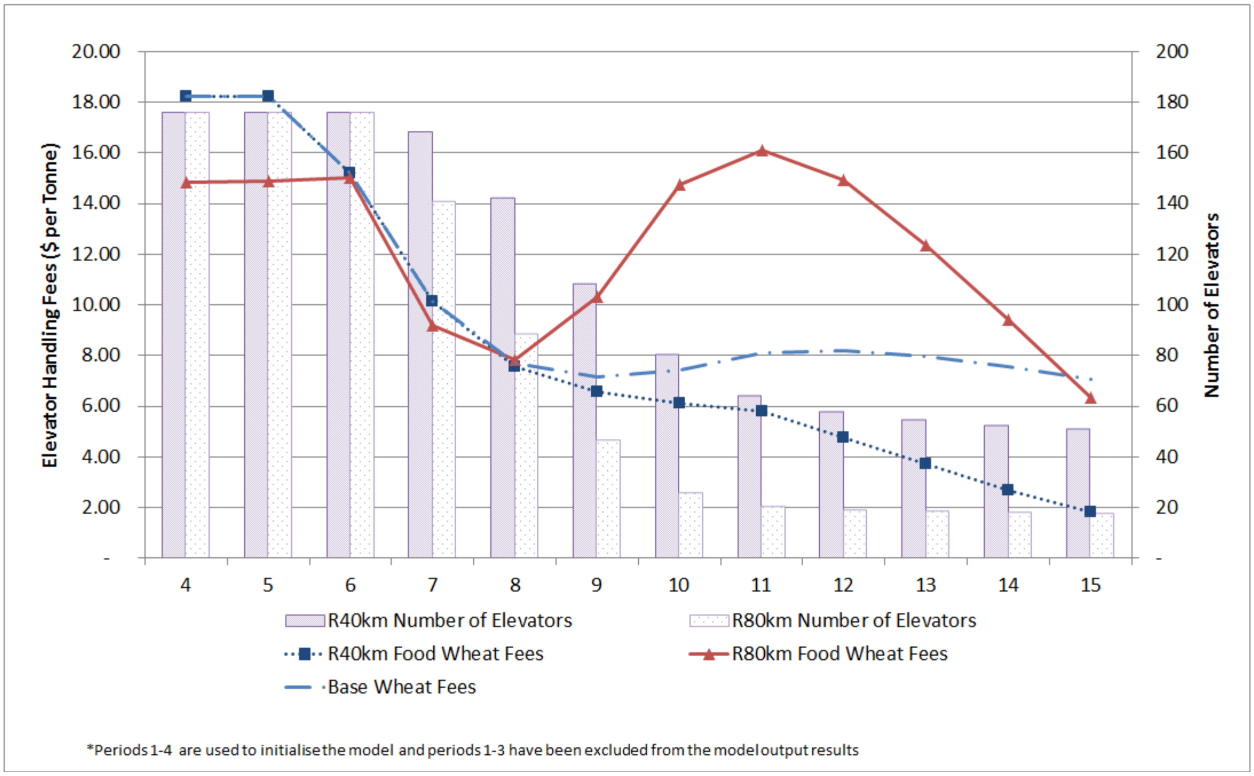

Figure 5.11: Simulated Mean Elevator Wheat Handling Fees and the Number of Elevators- 10% Growth in Crude Prices and Declining Biofuel Support (E10%-S18¢-R40km and E10%-S18¢-R80km).
Source: Created by author with data from the *FARMCHAIN* model.

5.4 Summary Discussion of Cropland Allocation, Elevator Fee Behavior and Elevator Density

In this chapter, the *FARMCHAIN* agent based simulation model was both verified and validated. Verification was done using random sampling of outcomes and checking them for logical consistency and accuracy. Next, the *FARMCHAIN* model was validated by comparing several key variables, including mean simulated wheat production, wheat disposition, elevator fees, and cropping patterns, against historic mean values. The simulated results were found to be close to historic wheat production levels and farm cropping patterns. Simulated elevator fees were not close to historic 2010-11 levels, but this could be accounted for by the uncharacteristically high levels of handling fees for that crop year. Based prior work, it was believed that path dependency would not be a factor in terms of the spatial assignment of farms because of the large number of farmer agents and plots. This was found to be the case.

5.4.1 Cropland Allocation

In the next sections, the base and counterfactual scenario were delineated. A total of seven counterfactual scenarios were designed to test sectoral wheat production, elevator behavior and density against a continuation of current conditions (called the base scenario). Counterfactual variables were based on 1) differences in levels of spatial competition (40 and 80km), 2) differences in government biofuel support and (25 and 18¢/l), and 3) energy price trends (0 or a 10% increase per year). The base scenario is formed by the first value in each set of parentheses.

In terms of sector wheat production in the base scenario, after the period of initialization, mean food wheat production increased by 12.7% between periods 4 and 5 held relative steady for the remainder of the simulation. Reducing biofuel support to 18¢/l and keeping other variables at base, the reduced price that ethanol plants offered farmers caused biofuel/food wheat to be less/more attractive to farmers and resulted in a 81.6% decline/ 31.9% increase in biofuel/food wheat production. Under higher levels of spatial competition, biofuel wheat share of land allocation of 26% (under base biofuel support) and 20% (under declining biofuel support) was substantially above low competition shares of 20% (under base biofuel support) and 13% (under declining biofuel support), respectively. Higher biofuel wheat production resulted from the effect of intense competition in the earlier periods of the simulation that caused in significant industry ‘shakeout’. The remaining firms were able increase fees significantly which in turn led to farmers responding by seeding more biofuel wheat.

When oil prices increased persistently at 10% per year, ethanol plant operators were able to offer farmers a higher price. Over time, farmers adopted biofuel wheat as it became relatively more attractive than food wheat. Farmers begin to switch, in the aggregate, between periods 9 and 12. Future oil prices during these periods were set to within the range of $133.48 to $177.66 per barrel. In 2008, the year with the highest crude price on record, the annual average real crude price was approximately $104.[31] Placed in context, oil prices would have to be at least 28% over that of the 2008 crisis period to facilitate an aggregate shift in production to biofuel wheat. However, in general, the increased viability of biofuel wheat driven by increases in oil prices

[31] Source: Computed by author with data from Statistics Canada (2012) and NRCAN (2012)

minimally impacts the inter-crop competition between wheat and canola. Total wheat production was consistently between 7.9 and 8.2 million tonnes, with higher levels of production occurring under higher level of competition, after industry 'shakeout' occurred. [32]

Overall, mean food/biofuel wheat production is greater under lower/higher levels of spatial competition, declining/sustained biofuel industry support and there is no-growth/growth in real crude prices (Table 5.8). The reduction in food wheat production resulting from increased spatial competition varies between 464 thousand tonnes (under declining biofuel support and no growth in oil prices) and 77 thousand tonnes (under sustained biofuel support and 10% growth in oil prices). On the other hand, increased spatial competition increases biofuel wheat production between 129 thousand tonnes (under declining biofuel support and no growth in oil prices) and 553 thousand tonnes (under sustained biofuel support and 10% growth in oil prices). This indicates that increased spatial competition favours the biofuel industry more than it would hurt the food wheat handling sector. This may provide valuable intuition into policy, as policies that increase competition in the food handling sector may lead to net benefits to wheat production as a whole.

When biofuel industry support declines, food wheat production increases by between 473 thousand and 627 thousand tonnes (the difference between scenarios 5 and 7 and scenarios 6 and 8, respectively, in Table 5.8). Alternatively, biofuel wheat production declines by between 468 thousand (the difference between scenarios 5 and 7) and 629 thousand tonnes (the difference between scenarios 6 and 8). From a policy perspective, policies geared toward sustaining or increasing wheat production is not viable if biofuel support is declining, crude oil prices are growing and the level of spatial competition between elevators is low because the benefit in food wheat production would be negated by the loss in biofuel wheat production thereby resulting in a net reduction in wheat production.

[32] It is suspected that intercrop competition was constrained by the historical land allocation constraints.

Table 5.9: Summary of Simulated Wheat Production by Scenario

Scenario Number	Scenario Reference Name	Food Wheat Production				
		Beginning Production Level in Tonnes	Ending Production Level in Tonnes	Mean Production Level in Tonnes	Highest Production Level in Tonnes (Year)	Lowest Production Level in Tonnes (Year)
1 (Base)	E0%-S25¢-R40km	5,761,169	7,094,871	6,376,039	7,094,871 (Period 15)	5,761,169 (Period 4)
2	E0%-S25¢-R80km	5,777,934	5,879,540	5,930,684	6,648,159 (Period 6)	5,132,643 (Period 14)
3	E0%-S18¢-R40km	5,761,169	7,596,601	6,921,876	7,651,027 (Period 14)	5,761,169 (Period 4)
4	E0%-S18¢-R80km	5,777,934	6,906,846	6,457,855	6,906,846 (Period 15)	5,777,934 (Period 4)
5	E10%-S25¢-R40km	5,761,169	619,233	3,953,636	6,491,616 (Period 5)	619,233 (Period 15)
6	E10%-S25¢-R80km	5,777,934	420,758	3,877,036	6,611,476 (Period 5)	420,758 (Period 15)
7	E10%-S18¢-R40km	5,761,169	1,441,607	4,581,033	6,491,616 (Period 5)	1,441,607 (Period 15)
8	E10%-S18¢-R80km	5,777,934	1,250,628	4,349,935	6,611,476 (Period 5)	1,250,628 (Period 15)
Scenario Number	Scenario Reference Name	Biofuel Wheat Production				
		Beginning Production Level in Tonnes	Ending Production Level in Tonnes	Mean Production Level in Tonnes	Highest Production Level in Tonnes (Year)	Lowest Production Level in Tonnes (Year)
1 (Base)	E0%-S25¢-R40km	2,164,556	876,556	1,567,024	2,164,556 (Period 4)	876,556 (Period 15)
2	E0%-S25¢-R80km	2,152,023	2,237,125	2,091,358	2,978,555 (Period 14)	1,243,161 (Period 6)
3	E0%-S18¢-R40km	2,164,556	398,103	1,028,419	2,164,556 (Period 4)	332,908 (Period 14)
4	E0%-S18¢-R80km	2,152,023	1,241,691	1,581,571	2,152,023 (Period 4)	1,241,691 (Period 15)
5	E10%-S25¢-R40km	2,164,556	7,365,971	3,991,858	7,365,971 (Period 15)	1,411,784 (Period 5)
6	E10%-S25¢-R80km	2,152,023	7,628,042	4,121,307	7,628,042 (Period 15)	1,288,367 (Period 5)
7	E10%-S18¢-R40km	2,164,556	6,533,685	3,363,208	6,533,685 (Period 15)	1,411,784 (Period 5)
8	E10%-S18¢-R80km	2,152,023	6,801,101	3,653,400	6,801,101 (Period 15)	1,288,367 (Period 5)

Source: Created by author with data from the *FARMCHAIN* model.

5.4.2 Elevator Behaviour and Density

It is clear from this work that elevator market structure matters and that market structure influences overall pricing behaviour. When spatial competition was extended to 80 km, the combination of 1) predatory elevator behavior and 2) ethanol feedstock prices and the effect of fees on farmers' gross margin expectations create dynamically unstable elevator fee equilibria that resemble what was coined "roller coaster" phenomena, consisting of three phases: 1) elevator industry shakeout or market rationalization, 2) spatial monopsonistic pricing, and 3) and resumption of elevator competition. This is best exemplified by the dynamics of high spatial competitiveness displayed in the base energy price and government support scenario. At first, cutthroat competition depresses elevator fees. This in turn leads to an industry shakeout resulting in (many cases) less than 25 surviving elevators. These remaining elevators are located in 'donut' patterns, characterized by no surviving elevators in the middle of a spatial group of elevators. Subsequently, industry shakeout is followed by a shift for the remaining elevators to monopsonistic pricing of elevator fees, ratcheting elevator fees to higher and higher levels. Farmers then realize lower food wheat returns due to higher handling and transportation fees and thus switch from food to biofuel wheat. This conversion ensues in declining food wheat supplies, eventually leading to a return to greater elevator competition over time with lower handling fees.

Diminished government biofuel subsidy and/or increasing oil prices can also alter the speed and type of dynamic adjustments under increased spatial competition. While a diminished government biofuel subsidy does not have much effect, major increases in energy prices such as those associated with the assumed 10%/year increase in oil price scenario can. In the latter case, the initial dynamics are similar to that generated by the low (R40 km) spatial competition scenario. However, the impact of steadily increasing biofuel wheat prices dramatically diminishes food supplies, forcing elevators to shift from their previous role of spatial monopsonists and to vigorously reassume the role of cutthroat or carnivorous competitors so that elevator fees are driven down once again.

In general, as shown in Table 5.9, the rate of elevator survival declines with increased spatial competition but increases when spatial competition is high and biofuel industry support is declining. Elevator tariff rises to its highest when crude oil prices are not growing and biofuel industry support is declining and spatial competition is high but falls to its lowest when crude oil prices are increasing, biofuel industry support is sustained and spatial competition is low.

Table 5.10 Summary of Simulated Grain Elevator Performance, by Scenario

Scenario Number	Scenario Reference Name	Ending Mean Number of Elevators	Lowest Elevator Tariff in $/t [1/, 2/]		Highest Elevator Tariff in $/t [1/, 2/]		Ending Elevator Tariff ($/t)[1/]
1 (Base)	E0%-S25¢-R40km	52	$7.08	(Period 15)	$18.23	(Period 5)	$7.08
2	E0%-S25¢-R80km	17	$7.81	(Period 8)	$20.73	(Period 12)	$16.15
3	E0%-S18¢-R40km	54	$7.33	(Period 9)	$18.23	(Period 5)	$9.32
4	E0%-S18¢-R80km	18	$8.13	(Period 8)	$23.48	(Period 12)	$21.37
5	E10%-S25¢-R40km	50	$1.09	(Period 15)	$18.23	(Period 5)	$1.09
6	E10%-S25¢-R80km	16	$4.29	(Period 15)	$15.04	(Period 6)	$4.29
7	E10%-S18¢-R40km	50	$1.81	(Period 15)	$18.23	(Period 5)	$1.81
8	E10%-S18¢-R80km	17	$6.36	(Period 15)	$16.12	(Period 11)	$6.36

[1/]Elevator tariff is the mean tariff for food wheat. [2/]The time period for which the mean fees are charged are in ().

Source: Created by author with data from the *FARMCHAIN* model.

5.4.3 Discussions of the Key Assumptions Driving the *FARMCHAIN* Model

In brief review, two key assumptions that significantly influence the results of the *FARMCHAIN* simulation model. [33] The first assumption is that of no individual elevator capacity constraints. With no capacity constraints, elevators that are unable to attract a desired level of grain are duly forced to continue to reduce handling fees to attract grain, meaning that over time they will ultimately be forced to exit the industry. If there were capacity constraints in the model, elevators who can charge relatively lower handling fees would be filled to capacity, after which any excess supply of grain would then be received by other proximate elevators. It is believed that this assumption would increase the mean survival rate of elevator agents, resulting in more stable average handling fees for food wheat.

The second key assumption pertains to the internal rules governing elevator spatial competitiveness. It is assumed that elevators spatially compete for grain by modifying the prices offered to farmers. The degree of price adjustment in the simulation is assumed to be random and depends on the number of elevators that are in close proximity. This assumption may result in an overestimation of the magnitude of elevator price changes, although the direction is consistent with expectations.

[33] The assumption that wheat has only two primary end uses also imposes some limitation as biofuel production is somewhat overestimated. In general, if simulated biofuel wheat production could be adjusted downward to reflect current capacity levels, it is likely that the price at which farmers would be enticed to switch would increase.

Together, these assumptions likely result in a simulated elevator density that is too sparse to be realistic. Under the most extreme conditions of 80 km radius of spatial competition and a 10% annual increase in energy prices, extreme competition for diminishing food wheat supplies resulted in only 16 surviving elevators. The realism of this estimate has to be further examined. Using the simulated density, the average elevator would have a catchment radius of approximately 130 km with a total throughput of around 27,000 tonnes. The initial average throughput at the beginning of the simulation is approximately 35,000 tonnes. However in Scenario 4, where there is a significant decline to 18 surviving elevators but no marked decline in food wheat deliveries, the annual throughput would increase to approximately 390,000.[34] This would likely require a basic redesign of the surviving elevators and their associated rail track towards much higher throughput and a likely shift in function to that of an inland terminal. While storage and handling are subject to considerable economies of size, there are also considerable increases in transport costs from the farm and this could result significant increases in the demand for primary highways leading to the remaining delivery points. These are important considerations but are beyond the scope of this thesis.

The simulation results reported and discussed are underlaid by underlying energy, crop and other assumptions outlined. However, other exogenous shocks to the supply chain such as industrial action at the ports, increase rail freight rates due to increased market power or weather shocks that could change crop yield could significantly alter the model outcomes.

[34] This outcome is due to the assumptions driving spatial competition between elevators.

CHAPTER 6: SUMMARY AND CONCLUSIONS

6.1 Summary of the *FARMCHAIN* ABSM

This thesis used an agent based model to assess the impact of increasing future world oil prices, government biofuel support and levels of spatial competition on future Saskatchewan wheat production and elevator structure. The agent based model, *FARMCHAIN*, was comprised of over 35,000 farmer agents, 176 grain elevator agents, 5 ethanol plant agents, 6 crushing plant agents and a biodiesel plant agent placed on the 20 Saskatchewan census agricultural regions. In terms of behavioral assumptions, elevator and farmers behavior were fundamental to the *FARMCHAIN* model. Farmer agents were assumed to react according to their own individual expectations of net gross margin based on a weighted historical average: they choose a crop mix based on the comparative profitability of biofuel and food wheat; canola; barley; and field peas. Biofuel wheat was moved into the ethanol production chain while food wheat moves into a differing chain that includes both domestic and export markets. World commodity prices are assumed to be exogenous. Variable farm costs of production were static over time but transportation costs vary with energy costs. These costs and applicable elevator handling costs were deducted from the world price to form individual farmer agents' gross margins. The gross margins, along with the next period prices were used to formulate the farmers' expectations and the subsequent land allocation decisions of the next period.

Eight scenarios were delineated consisting of a base and seven counterfactuals according to two levels of three counterfactual variables. The scenarios were formed by 1) two levels of spatial competition between elevators (40 km and 80 km), 2) two annual oil price trends (none and 10% per year) and 3) two levels of government support to the biofuel industry (25¢/l and 18¢/l). Each scenario was simulated over a fifteen-period time horizon with the first four periods being used to initialize agent behavior and was replicated fifty times based on differing exogenous world price paths.

6.2 Counterfactual Conclusions

Expansion of the biofuel industry was sustainable only under increases in world crude oil prices. At sustained biofuel support, it was concluded that real annual crude prices would have to surpass $133 per barrel in order to entice farmers to switch from producing food wheat to producing biofuel wheat. Sustained government support to the biofuel industry was not sufficient to facilitate a significant change in the cropping behaviour of farmers. Increased elevator competition results in lower handling fees which in turn reduces the competitiveness of cropping biofuel wheat. Declining biofuel support reduced the inter-wheat competition which in turn alleviated the competitive pressure in the elevator industry, leading to increased food wheat production and a higher survival rate of elevators. Also, higher levels of spatial competition, led to overall higher levels of biofuel wheat production. Higher competition led to an accelerated decline in fees and subsequent elevator insolvencies. Surviving elevators were able to charge higher fees which led to producers seeding a relatively higher proportion of biofuel wheat.

An emergent result is that elevator market structure and elevator behavior matter in both elevator fees and in food versus biofuel production. The combination of increased competition from predatory elevator behavior and feed forward of prices and fees to farmer agent gross margin expectations creates dynamically unstable elevator fee equilibria that resemble a "roller coaster" of three stages. First, the initial increased level of spatial competition between elevators to an increased industry shakeout. After the industry shakeout occurred, the remaining elevators locations were spatially clustered in a *donut* shape, as the peripheral elevators which drove out interior elevators. In the second stage after the shakeout, dramatically reduced elevator numbers resulted in spatial monopsonistic fee pricing. In response food wheat production declined and, in the extreme case where increased oil prices led increased biofuel wheat prices, food wheat production considerably diminished (92.7% decline from the initialisation period). In the third stage, the rationalized market puts increasing pressure on elevators to resume competition resulting in lower elevator fees and somewhat higher food wheat production.[35]

6.3 Limitations and Suggestions for Further Study

The *FARMCHAIN* model is in some ways a "proof of concept" and the next generation of models should incorporate individual elevator capacity constraints and logistic decisions in grain movement in a manner similar to that of Lawrence (2011). In addition, *FARMCHAIN*

[35] Elevators would lose money if handling fees set were less than marginal costs. It was assumed that marginal costs were zero. Therefore on average elevators were not losing money.

incorporates relatively simplistic elevator behavior; further studies should explore alternative elevator company pricing behaviour in the post-single-desk-selling era. This could include more sophisticated differential pricing across the entire western Canadian prairie landscape. Under assumptions of spatial Bertrand pricing, it was shown that there could be a dramatic industry “shakeout” resulting in the surviving elevators capturing a many fold increase in market share. A further extension to this thesis would be to analyse the effect market collusion in such a setting. The accompanying increase in storage and throughput means that increased investment and adjustment costs should be incorporated into the elevator company decisions. In addition, the modelling of railway agents should also be incorporated in future research to assess the impact of their behaviour on the system and how other agents’ behaviours influence rail agent decisions.

Finally, technological and structural change at the farm level was excluded. If real oil prices consistently increase over time, it would be reasonable to assume that technology would adapt (for example the introduction more fuel efficient machinery) within the 12-year period. Thus this study could be merged with the work of Anderson (2012) in the future to assess the impact of increased food wheat competition on elevator behaviour.

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APPENDIX A: ECONOMIC MODELS OF SPATIAL COMPETITION

Modeling the impact of spatial relationships on behavioral outcomes has proven to be quite difficult due to the inherent complexities involved. The theoretical work of Hotelling (1929), Lösch (1954), D'Aspremont, Gabszewicz and Thisse (1979), Shaked (1982), Osborne and Pitchik (1986), and Dasgupta and Maskin (1986) provide frameworks through which agent behaviour may be explained based on spatial relationships. This section briefly highlights the key contribution of these authors to the literature on models of spatial competition.

Hotelling (1929) develops and solves a pricing model in which products are differentiated by firms' geographical location in the market. Location models are usually designed to identify the optimal location of sellers on a spatially uniformed continuum of consumers. This optimal location of the selling firm is influenced by the price set by the firm and the consumers' transportation costs to that firm. Firms may either alter their position or prices in order to maximize market share which in turn maximizes profits. Hotelling found that in a case of only two firms the equilibrium would be that firms locate in the centre of the market. Hotelling's notion of firm agglomeration (to the centre) in the case of two firms is refuted by Lösch (1954). Lösch indicates that the Hotelling solution only holds in an isolated case under a set of unrealistic assumptions. He further notes that agglomeration only takes place if firms do not react to its competitors' actions and if the demand for the commodity is inelastic. Further refuting the findings of Hotelling, D'Apremont *et al.* (1979) highlighted that there is no equilibrium when the two firms are close to each other. They further stated that, with some minor alterations to Hotelling's model, an equilibrium could exist everywhere on the linear city continuum. Rasmusen (2007) indicates that the collapse of the Hotelling model is due to the fact that there are discontinuities in the firms' objective functions and as such, Hotelling only computes a local optimum which is different from the global optimum.

Hotelling however noted that when there were more than two firms there is no pure strategy Nash equilibrium as firms on the periphery would want to move toward the centre whilst those on the interior would want to increase market share by moving to the periphery. In this regard, Lösch indicates that if the one-dimensional line was substituted for a two-dimensional plane and there are more than two competing firms, then at the optimum, firms would be equidistant from each other. The works of Shaked (1982), Dasgupta and Maskin (1986), and Osborne and Pitchik (1987) highlight the existence of a mixed strategy equilibrium in firm location. Shaked highlighted that the three-firm location problem does indeed have a mixed strategy Nash equilibrium. The author's finding implies that firms in equilibrium will stay away from extreme quartiles and choose locations in the remaining half with equal probability. Dasgupta and Maskin derived two existence theorems for the mixed-strategy equilibrium in games with discontinuous payoff functions. The authors used the examples of the Bertrand pricing game with capacity constraints (which has a discontinuous payoff function) and the Hotelling location model to show the existence of a mixed-strategy equilibrium in firm location. Osborne and Pitchik expand on the work of Dasgupta and Maskin and noted that the search for an equilibrium could be reduced to solving at most three non-linear equations. The authors found that a there exists both pure strategy and mixed strategy subgame perfect equilibria in location choices of the firms.

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APPENDIX B: LIST OF TABLES

Table B-1: *FARMCHAIN* Crop Land Allocation Coefficients Associated with corner point solutions of the Farmer Agent Optimization Problem.

	MAX WHEAT&MAX BARLEY[a]				MAX WHEAT&MAX FIELD PEAS[b]				MAX CANOLA&MAX BARLEY[c]				MAX CANOLA&MAX FIELD PEAS[d]			
CAR	WHEAT	CANOLA	BARLEY	FIELD PEAS	WHEAT	CANOLA	BARLEY	FIELD PEAS	WHEAT	CANOLA	BARLEY	FIELD PEAS	WHEAT	CANOLA	BARLEY	FIELD PEAS
1a	0.44	0.29	0.18	0.09	0.45	0.30	0.15	0.11	0.36	0.37	0.18	0.09	0.37	0.38	0.15	0.11
1b	0.51	0.23	0.20	0.06	0.51	0.23	0.19	0.08	0.38	0.40	0.17	0.05	0.37	0.40	0.16	0.07
2a	0.52	0.19	0.19	0.11	0.51	0.19	0.17	0.13	0.29	0.42	0.18	0.11	0.29	0.42	0.16	0.13
2b	0.45	0.17	0.22	0.16	0.43	0.16	0.18	0.22	0.24	0.44	0.18	0.14	0.23	0.43	0.15	0.19
3an	0.57	0.12	0.18	0.12	0.51	0.11	0.09	0.28	0.51	0.20	0.17	0.12	0.46	0.18	0.09	0.27
3as	0.56	0.07	0.17	0.20	0.53	0.07	0.06	0.35	0.38	0.22	0.18	0.22	0.36	0.21	0.06	0.37
3bn	0.40	0.06	0.24	0.31	0.43	0.06	0.10	0.41	0.28	0.16	0.25	0.31	0.30	0.17	0.11	0.42
3bs	0.44	0.03	0.21	0.33	0.44	0.03	0.21	0.33	0.31	0.07	0.24	0.38	0.31	0.07	0.24	0.38
4a	0.58	0.04	0.28	0.11	0.57	0.04	0.17	0.21	0.53	0.09	0.28	0.11	0.52	0.09	0.18	0.22
4b	0.56	0.06	0.15	0.22	0.61	0.07	0.05	0.27	0.49	0.13	0.16	0.23	0.53	0.14	0.05	0.28
5a	0.43	0.27	0.23	0.07	0.43	0.27	0.22	0.08	0.28	0.43	0.22	0.07	0.28	0.43	0.21	0.08
5b	0.41	0.28	0.24	0.06	0.41	0.28	0.22	0.09	0.26	0.45	0.23	0.06	0.26	0.45	0.21	0.09
6a	0.44	0.20	0.23	0.12	0.45	0.20	0.22	0.13	0.28	0.40	0.21	0.11	0.28	0.40	0.20	0.11
6b	0.53	0.19	0.22	0.06	0.54	0.19	0.13	0.14	0.36	0.33	0.24	0.07	0.37	0.34	0.14	0.15
7a	0.51	0.14	0.29	0.06	0.54	0.15	0.16	0.15	0.40	0.23	0.31	0.07	0.42	0.24	0.17	0.16
7b	0.52	0.21	0.19	0.08	0.53	0.22	0.11	0.14	0.39	0.31	0.20	0.09	0.41	0.32	0.12	0.15
8a	0.40	0.29	0.20	0.10	0.40	0.29	0.20	0.10	0.29	0.42	0.19	0.10	0.29	0.42	0.19	0.10
8b	0.43	0.25	0.27	0.05	0.44	0.26	0.19	0.11	0.26	0.44	0.25	0.05	0.26	0.46	0.18	0.10
9a	0.37	0.31	0.24	0.08	0.39	0.33	0.17	0.11	0.30	0.38	0.23	0.08	0.32	0.41	0.16	0.10
9b	0.40	0.31	0.23	0.06	0.39	0.30	0.19	0.12	0.33	0.39	0.22	0.06	0.33	0.39	0.18	0.11

[a] Shows the crop land allocation for wheat, canola, barley and field peas if , for any given farmer, **the expected price is greater for wheat than that of canola and barley is greater than that of field peas.**

[b] Shows the crop land allocation for wheat, canola, barley and field peas if , for any given farmer, **the expected price is greater for wheat than that of canola and barley is less than that of field peas.**

[c] Shows the crop land allocation for wheat, canola, barley and field peas if , for any given farmer, **the expected price is less for wheat than that of canola and barley is greater than that of field peas.**

[d] Shows the crop land allocation for wheat, canola, barley and field peas if , for any given farmer, **the expected price is less for wheat than that of canola and barley is less than that of field peas.**

Source: Constructed by author with data from Saskatchewan Ministry of Agriculture (2012)

Table B-2: Agent location and Geodesic Distances to Ports or Biodiesel Plant

Agent-Type	Location	Company	latitude	longitude	DistanceTB	DistanceVC	DistanceBD
Crushing Plant	Clavet	Cargill Limited	51.997357	-106.374119	1273	1217	199
Crushing Plant	Nipawin	Bunge Canada	53.356744	-104.026285	1164	1399	194
Crushing Plant	Watson	ADM Agri-Industries Company	52.12651	-104.521329	1153	1344	86
Crushing Plant	Yorkton	LDM Yorkton Trading LP	51.204055	-102.449874	990	1481	89
Crushing Plant	Yorkton	Richardson Group	51.204055	-102.449874	990	1481	89
Crushing Plant	Foam Lake	Milligan Bio-Tech Inc.	51.639305	-103.539387	1074	1407	0
Biodiesel Plant	Foam Lake	Milligan Bio-Tech Inc.	51.639305	-103.539387		1407	
Grain Elevator	Aberdeen	Louis Dreyfus Canada Ltd.	52.328581	-106.291477	1276	1228	
Grain Elevator	Alameda	Viterra Inc.	49.266715	-102.282344	952	1506	
Grain Elevator	Amazon	Parrish & Heimbecker, Limited	51.535	-105.438	1200	1275	
Grain Elevator	Antelope	South West Terminal Ltd.	50.0998	-108.490429	1400	1054	
Grain Elevator	Antler	Richardson Group	49.377195	-103.193019	1019	1439	
Grain Elevator	Arborfield	Can Pro Ingredients Ltd.	53.10375	-103.660789	1131	1417	
Grain Elevator	Asquith	Bioriginal Food & Science Corp.	52.132725	-107.229434	1334	1161	
Grain Elevator	Assiniboia	PATERSON GRAIN	49.63284	-105.993119	1221	1235	
Grain Elevator	Assiniboia	Viterra Inc.	50.803325	-106.145899	1238	1221	
Grain Elevator	Balcarres	Cargill Limited	50.803565	-103.542339	1056	1404	
Grain Elevator	Balgonie	Richardson Group	50.48926	-104.268869	1103	1353	
Grain Elevator	Balgonie	Viterra Inc.	50.48926	-104.268869	1103	1353	
Grain Elevator	Belle Plaine	Terra Grain Fuels Inc.	50.47	-105.152448	1165	1291	
Grain Elevator	Bethune	Mobil Grain Ltd.	50.712126	-105.209736	1171	1287	
Grain Elevator	Biggar	Prairie Malt Limited	52.063855	-107.987089	1383	1109	
Grain Elevator	Biggar	Viterra Inc.	52.063855	-107.987089	1383	1109	
Grain Elevator	Birch Hills	Cargill Limited	52.98329	-105.438394	1239	1298	
Grain Elevator	Booth Siding	Viterra Inc.	51.793	-103.119	1050	1437	
Grain Elevator	Brada	Viterra Inc.	52.745	-108.239	1414	1109	
Grain Elevator	Brass	Louis Dreyfus Canada Ltd.	53.441	-105.338	1249	1316	
Grain Elevator	Bruno	Viterra Inc.	52.26536	-105.527124	1223	1278	
Grain Elevator	Cabri	Richardson Group	50.620475	-108.456889	1399	1058	
Grain Elevator	Canora	Richardson Group	51.635456	-102.432431	1000	1483	
Grain Elevator	Canora	Viterra Inc.	51.635456	-102.432431	1000	1483	
Grain Elevator	Carievale	PATERSON GRAIN	49.177415	-101.630784	905	1555	
Grain Elevator	Carnduff	PATERSON GRAIN	49.177225	-101.799049	917	1543	
Grain Elevator	Carnduff	Viterra Inc.	49.177225	-101.799049	917	1543	
Grain Elevator	Carrot River	Richardson Group	53.28336	-103.587534	1134	1426	
Grain Elevator	Carrot River	Viterra Inc.	52.86726	-103.648749	1121	1414	
Grain Elevator	Chamberlain	Mobil Grain Ltd.	50.85169	-105.569114	1198	1262	
Grain Elevator	Clavet	Cargill Limited	51.997357	-106.374119	1273	1217	
Grain Elevator	Congress	Cargill Limited	49.756625	-106.024604	1223	1232	
Grain Elevator	Corinne	Richardson Group	50.01	-104.547	1118	1336	
Grain Elevator	Coronach	Richardson Group	49.113815	-105.522614	1188	1275	
Grain Elevator	Creelman	Fill-More Seeds Inc.	49.82087	-103.309714	1029	1426	
Grain Elevator	Crooked River	Richardson Group	52.836789	-103.725335	1125	1408	
Grain Elevator	Cupar	Viterra Inc.	50.95029	-104.211624	1105	1357	
Grain Elevator	Dalmeny	Viterra Inc.	52.339287	-106.776637	1308	1196	
Grain Elevator	Davidson	Cargill Limited	51.267365	-105.995989	1234	1234	
Grain Elevator	Davidson	Richardson Group	51.267365	-105.995989	1234	1234	
Grain Elevator	Davidson	Viterra Inc.	51.267365	-105.995989	1234	1234	
Grain Elevator	Dixon	Bunge Canada	52.208	-105.301	1207	1293	
Grain Elevator	Dixon	Richardson Group	52.208	-105.301	1207	1293	
Grain Elevator	Dodsland	Prairie West Terminal Ltd.	51.79983	-108.839254	1437	1046	
Grain Elevator	Elrose	Viterra Inc.	51.201285	-108.027259	1374	1092	
Grain Elevator	Estevan	Richardson Group	49.14005	-102.993899	1004	1457	
Grain Elevator	Eyebrow	Viterra Inc.	50.802485	-106.149829	1238	1221	
Grain Elevator	Fairlight	Viterra Inc.	49.851	-101.558	903	1551	
Grain Elevator	Fillmore	Fill-More Seeds Inc.	49.882425	-103.432064	1038	1417	
Grain Elevator	Fillmore	Fill-More Seeds Inc.	49.882425	-103.432064	1038	1417	
Grain Elevator	Fillmore	Fill-More Seeds Inc.	49.882425	-103.432064	1038	1417	
Grain Elevator	Foam Lake	Viterra Inc.	51.639305	-103.539387	1074	1407	
Grain Elevator	Fox Valley	PATERSON GRAIN	50.463875	-109.486929	1471	984	
Grain Elevator	Glenavon	Fill-More Seeds Inc.	50.195005	-103.142604	1020	1435	
Grain Elevator	Goodeve	Richardson Group	51.060495	-103.186134	1037	1429	
Grain Elevator	Grand Coulee	Wigmore Farms Ltd.	50.43091	-104.817774	1141	1315	
Grain Elevator	Gravelbourg	Mustard Capital Inc.	49.873365	-106.554449	1261	1193	
Grain Elevator	Grenfell	PATERSON GRAIN	50.410585	-102.922609	1007	1449	
Grain Elevator	Grenfell	Viterra Inc.	50.410585	-102.922609	1007	1449	
Grain Elevator	Gull Lake	Viterra Inc.	50.055	-108.598519	1408	1046	
Grain Elevator	Hague	Viterra Inc.	52.326	-106.585	1295	1208	
Grain Elevator	Hamlin	Parrish & Heimbecker, Limited	52.76457	-108.313694	1420	1104	
Grain Elevator	Hamlin	Richardson Group	52.86684	-108.318062	1422	1107	
Grain Elevator	Herbert	PATERSON GRAIN	50.42715	-107.219164	1311	1144	
Grain Elevator	Hodgeville	Viterra Inc.	50.14213	-106.283823	1243	1211	
Grain Elevator	Humboldt	Viterra Inc.	52.2019	-105.121469	1195	1305	
Grain Elevator	Indian Head	PATERSON GRAIN	50.53177	-103.678799	1062	1395	

Latitude and longitude refer to the geographic coordinates of the agent-type. DistanceTB, DistanceVC and DistanceBD refer to the geodesic distances from the agent-type to the Thunder Bay Port, Vancouver Port and bio-diesel plant, respectively.

Table B-2 (Cont'd): Agent location and Geodesic Distances to Ports or Biodiesel Plant

Agent-Type	Location	Company	latitude	longitude	DistanceTB	DistanceVC	DistanceBD
Grain Elevator	Indian Head	PATERSON GRAIN	50.53177	-103.678799	1062	1395	
Grain Elevator	Ituna	Viterra Inc.	51.171315	-103.495779	1060	1408	
Grain Elevator	Kamsack	Richardson Group	51.56481	-101.903199	963	1519	
Grain Elevator	Kamsack	Viterra Inc.	51.56481	-101.903199	963	1519	
Grain Elevator	Kegworth	Louis Dreyfus Canada Ltd.	50.163	-102.996	1009	1445	
Grain Elevator	Kelvington	Viterra Inc.	51.34266	-102.891089	1023	1450	
Grain Elevator	Kindersley	Cargill Limited	51.47494	-109.167134	1455	1018	
Grain Elevator	Kindersley	Prairie West Terminal Ltd.	51.47494	-109.167134	1455	1018	
Grain Elevator	Kindersley	Viterra Inc.	51.47494	-109.167134	1455	1018	
Grain Elevator	Kipling	PATERSON GRAIN	50.101881	-102.623563	982	1472	
Grain Elevator	Lake Alma	Weyburn Inland Terminal Ltd.	49.14567	-104.196269	1092	1370	
Grain Elevator	Lake Lenore	Richardson Group	52.39727	-104.980336	1191	1317	
Grain Elevator	Landis	Viterra Inc.	52.19931	-108.455104	1417	1080	
Grain Elevator	Lang	PATERSON GRAIN	49.91992	-104.375144	1105	1349	
Grain Elevator	Langbank	Parrish & Heimbecker, Limited	50.048571	-102.302032	958	1496	
Grain Elevator	Langenburg	Viterra Inc.	50.836508	-101.682896	928	1535	
Grain Elevator	Lanigan	Pound-Maker Agventures Ltd.	51.845807	-105.036154	1180	1306	
Grain Elevator	Last Mountain S	Richardson Group	51.003	-104.902	1154	1309	
Grain Elevator	Leader	Great Sandhills Terminal Marketing Centre Ltd.	50.887035	-109.536504	1476	984	
Grain Elevator	Leross	Canada Malting Co. Limited	51.286085	-103.866769	1088	1382	
Grain Elevator	Limerick	PATERSON GRAIN	49.652695	-106.271159	1241	1215	
Grain Elevator	Lloydminster	Husky Oil Limited	53.285002	-110.023052	1544	1014	
Grain Elevator	Lloydminster	Viterra Inc.	53.27474	-109.997514	1542	1015	
Grain Elevator	Loreburn	Gardiner Dam Terminal Joint Venture	51.22866	-106.585969	1274	1193	
Grain Elevator	Luseland	Prairie West Terminal Ltd.	52.07949	-109.383469	1478	1016	
Grain Elevator	Luseland	Viterra Inc.	52.07949	-109.383469	1478	1016	
Grain Elevator	Maple Creek	Viterra Inc.	50.65827	-109.902784	1501	956	
Grain Elevator	Marengo	PATERSON GRAIN	51.48091	-109.777644	1498	976	
Grain Elevator	Marshall	Richardson Group	53.191865	-109.781199	1526	1025	
Grain Elevator	Melfort	Richardson Group	52.861365	-104.617954	1183	1350	
Grain Elevator	Melfort	Viterra Inc.	52.861365	-104.617954	1183	1350	
Grain Elevator	Melville	Viterra Inc.	50.93169	-102.818239	1009	1455	
Grain Elevator	Moose Jaw	Cargill Limited	50.401	-105.508	1189	1266	
Grain Elevator	Moose Jaw	Parrish & Heimbecker, Limited	50.388	-105.526	1190	1265	
Grain Elevator	Moose Jaw	Viterra Inc.	50.398	-105.522	1190	1265	
Grain Elevator	Moose Jaw	Viterra Inc.	50.46143	-105.57222	1194	1261	
Grain Elevator	Moosomin	Parrish & Heimbecker, Limited	50.489337	-104.255287	1102	1354	
Grain Elevator	Morse	Richardson Group	50.41448	-107.035884	1298	1157	
Grain Elevator	Mortlach	PATERSON GRAIN	50.45562	-106.067429	1229	1226	
Grain Elevator	Mortlach	R Young Seeds Inc.	50.45562	-106.067429	1229	1226	
Grain Elevator	Mossbank	RW Organic Ltd.	49.940255	-105.964394	1219	1235	
Grain Elevator	North Battleford	Cargill Limited	52.77574	-108.299064	1419	1106	
Grain Elevator	Naicam	CMI Terminal Joint Venture	52.420075	-104.497694	1160	1350	
Grain Elevator	Neville	Mission Terminal Inc.	49.961695	-107.626794	1338	1116	
Grain Elevator	Nicklen Siding	Bunge Canada	52.841805	-104.052919	1146	1387	
Grain Elevator	Nicklen Siding	Cargill Limited	52.841805	-104.052919	1146	1387	
Grain Elevator	Nokomis	Richardson Group	51.50991	-105.010099	1171	1304	
Grain Elevator	Northgate	Richardson Group	49.018997	-102.275099	952	1511	
Grain Elevator	Orkney	PATERSON GRAIN	49.14537	-107.911879	1362	1102	
Grain Elevator	Osage	Fill-More Seeds Inc.	49.95722	-103.579619	1049	1405	
Grain Elevator	Parkbeg	PATERSON GRAIN	50.452855	-106.264149	1243	1212	
Grain Elevator	Pense	Viterra Inc.	50.41497	-104.984669	1152	1303	
Grain Elevator	Plenty	Prairie West Terminal Ltd.	51.78295	-108.650174	1424	1058	
Grain Elevator	Prairie West	Prairie West Terminal Ltd.	50.447	-104.675655	1131	1325	
Grain Elevator	Prelate	PATERSON GRAIN	50.851965	-109.398014	1467	993	
Grain Elevator	Quill Lake	Parrish & Heimbecker, Limited	52.06813	-104.250389	1133	1362	
Grain Elevator	Radville	Prairie Heritage Seeds Inc.	49.460075	-104.294659	1098	1359	
Grain Elevator	Raymore	Cargill Limited	51.409265	-104.525384	1136	1337	
Grain Elevator	Redvers	Viterra Inc.	49.57627	-101.699144	911	1544	
Grain Elevator	Reed Lake	Richardson Group	52.841805	-104.052919	1146	1387	
Grain Elevator	Regina	CanMar Grain Products Ltd.	50.448015	-104.595179	1125	1330	
Grain Elevator	Regina	Oleet Processing Ltd.	50.448015	-104.595179	1125	1330	
Grain Elevator	Regina	Oleet Processing Ltd.	50.448015	-104.595179	1125	1330	
Grain Elevator	Regina East	Viterra Inc.	50.433	-104.491	1118	1338	
Grain Elevator	Richardson	PATERSON GRAIN	50.384753	-104.457392	1115	1340	
Grain Elevator	Rockhaven	Richardson Group	52.670565	-108.874329	1455	1065	
Grain Elevator	Rosetown	Cargill Limited	51.550285	-107.986949	1375	1100	
Grain Elevator	Rosetown	Viterra Inc.	51.55028	-107.98695	1375	1100	
Grain Elevator	Rowatt	Cargill Limited	50.342	-401.605	3403	5549	
Grain Elevator	Rowatt	Viterra Inc.	50.44474	-104.606519	1126	1330	
Grain Elevator	Saskatoon	Parrish & Heimbecker, Limited	52.087	-106.667	1295	1198	
Grain Elevator	Saskatoon	Parrish & Heimbecker, Limited	52.116	-106.721	1299	1195	
Grain Elevator	Saskatoon	Parrish & Heimbecker, Limited	52.144	-106.658	1296	1200	
Grain Elevator	Saskatoon	Richardson Group	52.082	-106.648	1294	1199	
Grain Elevator	Saskatoon	Viterra Inc.	52.114742	-106.736482	1300	1194	

Latitude and longitude refer to the geographic coordinates of the agent-type. DistanceTB, DistanceVC and DistanceBD refer to the geodesic distances from the agent-type to the Thunder Bay Port, Vancouver Port and bio-diesel plant, respectively.

Table B-2 (Cont'd): Agent location and Geodesic Distances to Ports or Biodiesel Plant (Cont'd)

Agent-Type	Location	Company	latitude	longitude	DistanceTB	DistanceVC	DistanceBD
Grain Elevator	Sedley	Wigmore Farms Ltd.	50.17025	-104.012884	1081	1373	
Grain Elevator	Shellbrook	Richardson Group	53.225976	-106.390965	1308	1242	
Grain Elevator	Stoughton	Viterra Inc.	49.681	-103.034	1008	1447	
Grain Elevator	Swift Current	PATERSON GRAIN	50.28233	-107.817809	1353	1102	
Grain Elevator	Swift Current	Richardson Group	50.28233	-107.817809	1353	1102	
Grain Elevator	Swift Current	Viterra Inc.	50.28233	-107.817809	1353	1102	
Grain Elevator	Tisdale	Louis Dreyfus Canada Ltd.	52.841805	-104.052919	1146	1387	
Grain Elevator	Tisdale	Parrish & Heimbecker, Limited	52.841825	-104.067939	1147	1386	
Grain Elevator	Tisdale	Viterra Inc.	52.841805	-104.052919	1146	1387	
Grain Elevator	Turtleford	Richardson Group	53.38847	-108.959079	1477	1084	
Grain Elevator	Unity	North West Terminal Ltd.	52.43711	-109.145549	1468	1041	
Grain Elevator	Unity	Viterra Inc.	52.43711	-109.145549	1468	1041	
Grain Elevator	Valparaiso	Viterra Inc.	52.86726	-103.648749	1121	1414	
Grain Elevator	Wadena	North East Terminal Ltd.	51.94262	-103.794739	1100	1392	
Grain Elevator	Wadena	Viterra Inc.	51.94262	-103.794739	1100	1392	
Grain Elevator	Wadena	Viterra Inc.	51.94262	-103.794739	1100	1392	
Grain Elevator	Wakaw	Richardson Group	52.65295	-105.742709	1248	1271	
Grain Elevator	Waldron	Viterra Inc.	50.85046	-102.515359	986	1476	
Grain Elevator	Watrous	Canada Malting Co. Limited	51.671625	-105.467879	1205	1274	
Grain Elevator	Weyburn	Richardson Group	49.66803	-103.858189	1067	1388	
Grain Elevator	Weyburn	Viterra Inc.	49.65773	-103.852249	1067	1389	
Grain Elevator	Weyburn	Weyburn Inland Terminal Ltd.	49.66803	-103.858189	1067	1388	
Grain Elevator	White Star	Viterra Inc.	53.206219	-105.753639	1267	1283	
Grain Elevator	Whitewood	Richardson Group	50.32783	-102.257894	959	1497	
Grain Elevator	Wilcox	PATERSON GRAIN	50.097268	-104.723091	1131	1323	
Grain Elevator	Wilkie	Viterra Inc.	52.406095	-108.713864	1439	1068	
Grain Elevator	Wolseley	PATERSON GRAIN	50.41964	-103.278914	1032	1424	
Grain Elevator	Woodrow	Viterra Inc.	49.6934	-106.722224	1274	1182	
Grain Elevator	Yellow Grass	Viterra Inc.	50.50224	-103.930663	1079	1377	
Grain Elevator	Yorkton	Cargill Limited	51.204055	-102.449874	990	1481	
Grain Elevator	Yorkton	Grain Millers Canada Corp.	51.204055	-102.449874	990	1481	
Grain Elevator	Yorkton	Parrish & Heimbecker, Limited	51.21205	-102.464082	991	1480	
Grain Elevator	Yorkton	Richardson Group	51.204055	-102.449874	990	1481	
Grain Elevator	Yorkton	Viterra Inc.	51.21205	-102.464082	991	1480	
Ethanol Plant	Belle Plaine	Terra Grain	50.401516	-105.172119		1291	
Ethanol Plant	Weyburn	NorAmera BioEnergy	49.667629	-103.859253		1389	
Ethanol Plant	Lloydminster	Husky Energy Inc.	53.271782	-109.995117		1019	
Ethanol Plant	Unity	Northwest Terminal Ltd	52.437595	-109.146423		1044	
Ethanol Plant	Lanigan	Pound-Maker Agventures ltd.	51.852745	-105.023804		1309	

Latitude and longitude refer to the geographic coordinates of the agent-type. DistanceTB, DistanceVC and DistanceBD refer to the geodesic distances from the agent-type to the Thunder Bay Port, Vancouver Port and bio-diesel plant, respectively.

Source: Created by author with data from Google Maps™ and www.cpearson.com

Table B-3: World Crop Prices Adjusted for Inflation and Converted to Canadian Dollars

	Wheat Price (CAN$/MT)	Barley Price (CAN$/MT)	Canola Price (CAN$/MT)	Field Peas Price (CAN$/MT)
1991	126.29	122.60	348.18	333.65
1992	160.60	140.65	301.92	302.23
1993	168.66	156.26	343.42	333.02
1994	169.76	146.09	370.52	276.96
1995	211.06	201.22	378.69	284.72
1996	274.16	247.36	404.68	344.27
1997	248.23	227.56	453.86	369.45
1998	205.77	175.50	431.53	301.12
1999	163.27	146.71	302.55	238.15
2000	166.91	168.54	286.71	239.18
2001	205.75	202.01	349.75	299.83
2002	185.93	171.99	370.60	321.21
2003	198.02	184.45	354.78	320.99
2004	195.86	175.23	339.31	269.66
2005	163.38	159.83	300.29	229.07
2006	176.22	159.16	321.53	230.20
2007	232.21	233.78	365.33	308.90
2008	303.95	304.51	528.49	544.86
2009	234.50	204.57	484.81	367.62
Max	303.95	304.51	528.49	544.86
Min	126.29	122.60	286.71	229.07
Mean	199.50	185.68	370.37	311.32
STD. DEV.	42.61	42.85	63.46	69.28
Skewness	0.81	1.15	1.02	1.92

Source: Created by author's calculations with data from Statistics Canada Table 176-0049, UN Comtrade (2012), Canola prices obtained from FAO STAT (2012)

Table B-4: Correlation Matrix of Crop Prices after Inflation adjustment, 1991- 2009

	Wheat	*Barley*	*Canola*	*Field Peas*
Wheat	1.00			
Barley	0.97	1.00		
Canola	0.81	0.74	1.00	
Field Peas	0.71	0.73	0.84	1.00

Source: Computed by author's calculations, with data from Table B-3.

Table B-5: Crop Price Auto-regression results

	Crop			
	Wheat	Barley	Canola	Field Peas
Constant	199.28 (0.00***)	184.06 (0.00***)	368.02 (0.00***)	303.24 (0.00***)
AR(1)	0.82 (0.00***)	0.77 (0.01***)	0.83 (0.00***)	
AR(2)	-0.60 (0.04**)	-0.73 (0.03**)	-0.75 (0.02**)	-0.81 (0.07**)
R-squared	0.46	0.44	0.54	0.21

P-values are in parentheses. ***indicates significance at the 1 % level,** indicates significance at the 5% level and * indicates significance at the 10% level

Source: Created by author’s calculations, with data from Table B-3.

Table B-6: Johansen Cointegration Test Result for Trucking Surcharge Estimation

Sample (adjusted): 5 104
Included observations: 100 after adjustments
Trend assumption: Linear deterministic trend
Series: LFTL LOILPRICE
Exogenous series: DUM
Warning: Critical values assume no exogenous series
Lags interval (in first differences): 1 to 3

Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	Critical Value	P-value**
None *	0.19	24.60	15.49	0.00
At most 1	0.03	2.97	3.84	0.09

Trace test indicates 1 cointegrating eqn(s) at the 0.05 level
* denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

Unrestricted Cointegration Rank Test (Maximum Eigenvalue)

Hypothesized No. of CE(s)	Eigenvalue	Statistic	Critical Value	P-value**
None *	0.19	21.63	14.26	0.00
At most 1	0.03	2.97	3.84	0.09

Max-eigenvalue test indicates 1 cointegrating eqn(s) at the 0.05 level
* denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

Unrestricted Cointegrating Coefficients (normalized by b'*S11*b=I):

LFTL	LOILPRICE
-25.82	26.81
-5.49	11.69

Unrestricted Adjustment Coefficients (alpha):

D(LFTL)	0.01	0.00
D(LOILPRICE)	-0.01	0.00

1 Cointegrating Equa Log likelihood 454.48

Normalized cointegrating coefficients (standard error in parentheses)

LFTL	LOILPRICE
1	-1.04
	(0.05)

Adjustment coefficients (standard error in parentheses)

D(LFTL)	-0.15
	(0.07)
D(LOILPRICE)	0.18
	(0.08)

Source: Author's Computations with data from National Traffic Services 2012 and EIA 2011b

Table B-7: Elevator Maximum Handling Fees in Used in the *FARMCHAIN* Model

	Wheat	Barley	Canola	Peas
Cargill				
Elevage	14.15	15.00	12.25	14.75
Storage	0.12	0.12	0.21	0.05
Cleaning	5.50	9.00	5.59	4.66
	19.77	24.12	18.05	19.46
Louis Dreyfus				
Elevage	14.00	15.50	16.50	18.00
Storage	0.12	0.15	0.16	0.13
Cleaning	5.50	8.50	5.75	6.00
	19.62	24.15	22.41	24.13
Patterson				
Elevage	13.99	14.72	18.00	19.00
Storage	0.12	0.15	0.22	0.12
Cleaning	4.49	5.99	5.99	5.99
	18.60	20.86	24.21	25.11
P&H				
Elevage	14.00	14.60	14.35	13.30
Storage	0.08	0.08	0.06	0.05
Cleaning	5.50	7.90	6.25	5.10
	19.58	22.58	20.66	18.45
Richardson				
Elevage	14.00	15.00	12.81	14.48
Storage	0.12	0.12	0.05	0.04
Cleaning	5.15	8.25	6.45	6.00
	19.27	23.37	19.31	20.52
Viterra				
Elevage	14.70	15.50	15.00	15.00
Storage	0.13	0.13	0.13	0.13
Cleaning	5.75	8.50	7.50	7.50
	20.58	24.13	22.63	22.63
Other				
Elevage	14.14	15.05	14.82	15.76
Storage	0.11	0.12	0.14	0.09
Cleaning	5.32	8.02	6.26	5.88
	19.57	23.20	21.21	21.72

Source: Computed by author with data from Canadian Grain Commission 2012

Table B-8: Johansen Cointegration Test Results for Cointegration between Gasoline and Oil Prices, 1991-2010

Series: GAS OIL
Lags interval (in first differences): 1 to 9
Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Statistic	Critical Value	Prob.**
None *	0.06	15.88	15.49	0.04
At most 1	0.00	0.95	3.84	0.33

Trace test indicates 1 cointegrating eqn(s) at the 0.05 level
* denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

Unrestricted Cointegration Rank Test (Maximum Eigenvalue)

Hypothesized No. of CE(s)	Eigenvalue	Statistic	Critical Value	Prob.**
None *	0.06	14.93	14.26	0.04
At most 1	0.00	0.95	3.84	0.33

Max-eigenvalue test indicates 1 cointegrating eqn(s) at the 0.05 level
* denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

Unrestricted Cointegrating Coefficients (normalized by b'*S11*b=I):

GAS	OIL
-0.43	0.24
0.08	0.00

Unrestricted Adjustment Coefficients (alpha):

D(GAS)	0.50	-0.14
D(OIL)	-0.45	-0.25

1 Cointegrating Equation(s): Log likelihood -1253

Normalized cointegrating coefficients (standard error in parentheses)

GAS	OIL
1	-0.56
	(0.03)

Adjustment coefficients (standard error in parentheses)

D(GAS)	-0.21
	(0.08)
D(OIL)	0.19
	(0.12)

Source: Author's computations with data from Statistics Canada CANSIM Table 326-0009

Table B-9: Johansen Cointegration Test Results for Cointegration between Diesel Fuel and Oil Prices, 1991-2010

Series: DIESEL OIL
Lags interval (in first differences): 1 to 2
Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Statistic	Critical Value	Prob.**
None *	0.12	36.09	20.26	0.00
At most 1	0.02	4.39	9.16	0.36

Trace test indicates 1 cointegrating eqn(s) at the 0.05 level
* denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

Unrestricted Cointegration Rank Test (Maximum Eigenvalue)

Hypothesized No. of CE(s)	Eigenvalue	Statistic	Critical Value	Prob.**
None *	0.12	31.70	15.89	0.00
At most 1	0.02	4.39	9.16	0.36

Max-eigenvalue test indicates 1 cointegrating eqn(s) at the 0.05 level
* denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

Unrestricted Cointegrating Coefficients (normalized by b'*S11*b=I):

DIESEL	OIL	C
-0.29	0.15	9.69
0.06	0.01	-4.44

Unrestricted Adjustment Coefficients (alpha):

D(DIESEL)	0.77	-0.10
D(OIL)	-0.02	-0.61

1 Cointegrating Equation(s): Log likelihoc -1246

Normalized cointegrating coefficients (standard error in parentheses)

DIESEL	OIL	C
1	-0.52	-33.14
	(0.03)	(1.48)

Adjustment coefficients (standard error in parentheses)

D(DIESEL)	-0.22
	(0.04)
D(OIL)	0.00
	(0.09)

Source: Author’s computations with data from Statistics Canada CANSIM Table 326-0009

Table B-10: Price Adjusted Wheat Premium Earned in and Quantities Supplied in Tonnes to the Japanese and Colombian Markets

Year	Premium Earned in Japan (US$/M.T.)	Quantity Supplied to Japan (Tonnes)	Premium Earned in Colombia (US$/M.T.)	Quantity Supplied to Colombia (Tonnes)
1988	53.75	1,337,878	N/A	N/A
1989	48.82	1,317,976	N/A	N/A
1990	37.60	1,279,914	N/A	N/A
1991	35.88	1,222,573	N/A	N/A
1992	27.27	1,409,423	N/A	N/A
1993	35.61	1,282,306	N/A	N/A
1994	32.26	1,378,530	N/A	N/A
1995	25.56	1,405,568	N/A	N/A
1996	33.44	1,314,959	N/A	N/A
1997	30.52	1,416,364	N/A	N/A
1998	33.85	1,324,481	N/A	N/A
1999	36.97	1,324,267	N/A	N/A
2000	37.02	1,295,569	18.68	427,796
2001	31.01	1,281,121	17.03	620,212
2002	24.16	1,220,581	13.78	415,592
2003	28.60	871,686	38.57	230,130
2004	30.72	963,724	5.03	505,453
2005	26.46	1,006,945	10.05	322,612
2006	24.20	985,144	23.52	331,160
2007	26.34	896,704	3.24	379,591
2008	57.16	971,986	67.18	208,988
2009	60.97	729,278	17.40	416,603
2010	36.29	840,421	8.34	535,542
2011	39.55	1,079,916	10.06	567,409

Source: Computed by author with data from UN Comtrade (2012)

Table B-11: Regression Results of Premiums on Canadian Wheat Exports to Japan

Dependent Variable: DTLP (Detrended Log of premiums)				
Method: Least Squares				
Sample (adjusted): 1989 2011				
Included observations: 23 after adjustments				
Variable	Coefficier	Std. Error	t-Statistic	Prob.
DTLQ(-1)	0.65	0.48	1.37	0.18
R-squared	0.08	Mean dependent var		-0.01
Adjusted R-squared	0.08	S.D. dependent var		0.21
S.E. of regression	0.20	Akaike info criterion		-0.31
Sum squared resid	0.90	Schwarz criterion		-0.26
Log likelihood	4.60	Hannan-Quinn criter.		-0.30
Durbin-Watson stat	1.50			
Premiums and Quatities supplied were trend stationary. Model was run with the constant term and no lags but DTLQ (the detrended log of quantities supplied) was still insignificant.				

Source: Author's computations refer to Table B-10

Table B-12: *FARMCHAIN* Model Simulation Output for Scenarios with Sustained Biofuel Support and No Growth in Crude Oil Prices

Sustained Biofuel Support and No Growth in Crude Oil Prices								
Time Period	Low Spatial Competition (R40km) [Base]				High Spatial Competition (R80km)			
	Food Wheat Production (Tonnes)	Biofuel Wheat Production (Tonnes)	Elevator Wheat Handling Fees ($/t)	Number of Elevators	Food Wheat Production (Tonnes)	Biofuel Wheat Production (Tonnes)	Elevator Wheat Handling Fees ($/t)	Number of Elevators
4	5,761,169	2,164,556	18.22	176	5,777,934	2,152,023	14.84	176
5	6,491,616	1,411,784	18.23	176	6,611,476	1,288,367	14.87	176
6	6,417,794	1,470,789	15.20	176	6,648,159	1,243,161	15.04	176
7	6,242,350	1,656,284	10.13	168	6,123,776	1,786,463	9.36	141
8	6,478,490	1,467,394	7.68	142	6,311,079	1,691,647	7.81	88
9	6,120,102	1,856,797	7.15	109	5,909,916	2,164,124	10.55	46
10	6,330,296	1,624,978	7.44	80	5,912,915	2,146,186	16.04	26
11	6,134,326	1,805,835	8.11	64	5,939,831	2,119,598	20.06	19
12	6,686,699	1,278,017	8.22	58	5,442,791	2,646,459	20.73	18
13	6,569,742	1,406,909	7.96	55	5,478,144	2,642,588	19.19	18
14	6,185,008	1,784,394	7.55	53	5,132,643	2,978,555	17.82	17
15	7,094,871	876,556	7.08	52	5,879,540	2,237,125	16.15	17
Periods 1-4 are used to initialise the model and periods 1-3 have been excluded from the model output results.								

Source: Created by author with data from the *FARMCHAIN* Model

Table B-13: *FARMCHAIN* Model Simulation Output for Scenarios with Declining Biofuel Support and No Growth in Crude Oil Prices

Declining Biofuel Support and No Growth in Crude Oil Prices								
Time Period	Low Spatial Competition (R40km) [Base]				High Spatial Competition (R80km)			
	Food Wheat Production (Tonnes)	Biofuel Wheat Production (Tonnes)	Elevator Wheat Handling Fees ($/t)	Number of Elevators	Food Wheat Production (Tonnes)	Biofuel Wheat Production (Tonnes)	Elevator Wheat Handling Fees ($/t)	Number of Elevators
4	5,761,169	2,164,556	18.22	176	5,777,934	2,152,023	14.84	176
5	6,491,616	1,411,784	18.23	176	6,611,476	1,288,367	14.87	176
6	6,417,794	1,470,789	15.20	176	6,648,159	1,243,161	15.04	176
7	6,530,290	1,368,273	10.13	168	6,387,473	1,522,786	9.36	141
8	6,859,279	1,086,337	7.82	142	6,480,985	1,523,431	8.13	88
9	6,517,746	1,459,266	7.33	109	6,213,724	1,864,780	11.42	47
10	7,130,800	835,612	7.93	81	6,601,745	1,468,012	18.62	26
11	7,251,111	699,272	8.72	65	6,174,211	1,915,729	23.02	20
12	7,252,317	720,968	9.26	59	6,745,684	1,381,801	23.48	18
13	7,602,758	393,160	9.24	57	6,527,482	1,638,168	23.33	18
14	7,651,027	332,908	9.26	55	6,418,547	1,738,904	22.52	18
15	7,596,601	398,103	9.32	54	6,906,846	1,241,691	21.37	18
Periods 1-4 are used to initialise the model and periods 1-3 have been excluded from the model output results.								

Source: Created by author with data from the *FARMCHAIN* Model

Table B-14: *FARMCHAIN* Model Simulation Output for Scenarios with Sustained Biofuel Support and 10% per Annum Growth in Crude Oil Prices

Sustained Biofuel Support and 10%/Year Growth in Crude Oil Prices								
Time Period	Low Spatial Competition (R40km) [Base]				High Spatial Competition (R80km)			
	Food Wheat Production (Tonnes)	Biofuel Wheat Production (Tonnes)	Elevator Wheat Handling Fees ($/t)	Number of Elevators	Food Wheat Production (Tonnes)	Biofuel Wheat Production (Tonnes)	Elevator Wheat Handling Fees ($/t)	Number of Elevators
4	5,761,169	2,164,556	18.22	176	5,777,934	2,152,023	14.84	176
5	6,491,616	1,411,784	18.23	176	6,611,476	1,288,367	14.87	176
6	6,115,117	1,774,342	15.20	176	6,353,014	1,539,293	15.04	176
7	5,295,549	2,605,589	10.12	168	5,382,930	2,529,279	9.21	141
8	5,241,574	2,707,066	7.43	142	5,265,423	2,737,634	7.63	88
9	4,425,505	3,552,173	6.22	109	4,498,120	3,569,259	9.58	46
10	3,903,849	4,057,547	5.58	80	3,713,002	4,339,786	13.52	25
11	3,606,512	4,337,419	5.10	64	3,006,697	5,030,105	15.00	19
12	2,328,000	5,633,048	4.10	56	2,188,354	5,848,785	12.78	18
13	1,969,371	6,011,581	2.99	53	1,844,019	6,211,401	9.58	17
14	1,686,138	6,281,226	1.97	51	1,462,703	6,581,716	6.77	17
15	619,233	7,365,971	1.09	50	420,758	7,628,042	4.29	16
Periods 1-4 are used to initialise the model and periods 1-3 have been excluded from the model output results.								

Source: Created by author with data from the *FARMCHAIN* Model

Table B-15: *FARMCHAIN* Model Simulation Output for Scenarios with Declining Biofuel Support and 10% per Annum Growth in Crude Oil Prices

Declining Biofuel Support and 10%/Year Growth in Crude Oil Prices								
Time Period	Low Spatial Competition (R40km) [Base]				High Spatial Competition (R80km)			
	Food Wheat Production (Tonnes)	Biofuel Wheat Production (Tonnes)	Elevator Wheat Handling Fees ($/t)	Number of Elevators	Food Wheat Production (Tonnes)	Biofuel Wheat Production (Tonnes)	Elevator Wheat Handling Fees ($/t)	Number of Elevators
4	5,761,169	2,164,556	18.22	176	5,777,934	2,152,023	14.84	176
5	6,491,616	1,411,784	18.23	176	6,611,476	1,288,367	14.87	176
6	6,115,117	1,774,342	15.20	176	6,353,014	1,539,293	15.04	176
7	5,497,311	2,403,441	10.12	168	5,558,055	2,353,910	9.21	141
8	5,521,144	2,425,649	7.54	142	5,378,091	2,625,514	7.83	88
9	4,947,148	3,030,741	6.55	108	4,587,400	3,481,247	10.33	46
10	4,922,666	3,035,318	6.13	80	4,800,128	3,259,505	14.76	25
11	4,298,622	3,646,706	5.80	64	4,031,511	4,012,027	16.12	20
12	4,197,471	3,761,137	4.76	57	3,023,484	5,029,302	14.93	19
13	3,242,820	4,735,449	3.73	54	2,808,706	5,266,895	12.36	18
14	2,535,709	5,435,689	2.66	52	2,018,786	6,031,621	9.41	18
15	1,441,607	6,533,685	1.81	50	1,250,628	6,801,101	6.36	17
Periods 1-4 are used to initialise the model and periods 1-3 have been excluded from the model output results.								

Source: Created by author with data from the *FARMCHAIN* Model

APPENDIX C: NETLOGO© CODES AND MODEL DATA

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;;;;;;;;;;;;;;;;;;;;;;;;;;;;; FARMCHAIN MODEL ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;


extensions[gis]
globals [skcar-dataset
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         c2a-dataset  c2b-dataset
         c3an-dataset c3as-dataset
         c3bn-dataset c3bs-dataset
         c4a-dataset  c4b-dataset
         c5a-dataset  c5b-dataset
         c6a-dataset  c6b-dataset
         c7a-dataset  c7b-dataset
         c8a-dataset  c8b-dataset
         c9a-dataset  c9b-dataset
         sksoil-dataset
         cargill-dataset
         louisd-dataset
         patterson-dataset
         pnh-dataset
         richardson-dataset
         viterra-dataset
         otherges-dataset
         cp-dataset
         ep-dataset
         bd-dataset
         roa-dataset
         rla-dataset
         town-dataset

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         realworld-height
         xfactor
         yfactor


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         pcanenergy
         wpsw
         wpbar
         wpcan
         wpfp

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         total-can-production
         total-fw-production
         total-fp-production
         total-bar-production

         all-ges
         grainhandlers
         patches-in-model
         ghwithcan ghw/ocan

         gewithsw  gew/osw
         gewithbar gew/obar
         gewithfp  gew/ofp
         cpwithcan cpw/ocan
         epwithfw  epw/ofw
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fwithsw  fw/osw
fwithbar fw/obar
fwithfp  fw/ofp
fwithcan fw/ocan
fwithfw  fw/ofw


SWVCsupply
SWTBsupply
SWdomsupply

barVCsupply
barTBsupply
barTBsupplyt1
dtbbarsupply
dtbbarpremt
bardomsupply
pvcbart
ptbbart


fpVCsupply
fpTBsupply
fpdomsupply

CANVCsupply
CANTBsupply
CANBDsupply

diesel-demand
Biodiesel_demand
Biodsupply
tot-exp-Biodsupply
pdt
pbdt
bdmargin
fbdp
Biod-fgpcan
pbdcant


fwsupply
ethsupply
total-dom-ethdemand
tot-exp-ethsupply
gasoline-demand
ethanol_demand
pgast
crude-price
petht
fethp
epmargin
meanethdemand
nsgreatd
pfwt
pfwt1


gebswlist
gebfplist
gebbarlist
gebcanlist
```

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fwpricelist
cppricelist
swprodlist
fwprodlist
ngelist
countges
avgebasissw
avgebasisfp
avgebasisbar
avgebasiscan


meangmsw
meangmcan
meangmbar
meangmfp
meangmfw

meanofcsw
meanofcbar
meanofccan
meanofcfp
meanofcfw

meangebasissw
meangebasisfp
meangebasisbar
meangebasiscan

meanrailcostSW
meanrailcostbar
meanrailcostcan
meanrailcostfp
meanrailcostfw

meantruckcostsw
meantruckcostbar
meantruckcostcan
meantruckcostfp
meantruckcostfw

meancopsw
meancopfp
meancopbar
meancopcan
meancopfw

landlist
discfactlist

wpswlist
wpbarlist
wpcanlist
wpfplist

year
runs
truck-surcharge
rail-surcharge

OFReast
OFRwest
```

```
          vcsw
          vcbar
          vcfp
          vcfw
          vccan

]

breed [roas   roa]
breed [rlas rla]
breed [towns town]
breed [ports port]
breed [eps ep]
breed [cplants cplant]
breed [bds bd]
breed [cargills cargill]
breed [louisds louisd]
breed [pattersons patterson]
breed [pnhs pnh]
breed [richardsons richardson]
breed [viterras viterra]
breed [otherges otherge]
breed [farmers farmer]

patches-own [cid
             zone
             land-id
             ysw ycan yfw yfp ybar
             mwmbw
             mwmbc
             mwmbb
             mwmbf
             mwmfw
             mwmfc
             mwmfb
             mwmff
             mcmbw
             mcmbc
             mcmbb
             mcmbf
             mcmfw
             mcmfc
             mcmfb
             mcmff
             swfuel swfert swTVC
             canfuel canfert canTVC
             barfuel barfert barTVC
             fpfuel fpfert fpTVC
             fwfuel fwfert fwTVC
             swcop cancop fwcop fpcop barcop]

Farmers-own [myphi
             swr canr fwr fpr barr
             fallow
             fpfal canfal
             land
             discfact
             fstorsw fstorcan fstorfw fstorfp fstorbar
             fgpsw fgpcan fgpfw fgpfp fgpbar
             swa cana fwa fpa bara
             ranksw rankcan rankfw rankfp rankbar
             swy cany fwy fpy bary
             fgec-sw fghc-can fepc-fw fgec-fp fgec-bar
             trkdistsw trkdistcan trkdistfw trkdistfp trkdistbar
```

```
              truckcostsw truckcostcan truckcostfw truckcostfp truckcostbar
              trucksursw trucksurcan trucksurfw trucksurfp trucksurbar
              tottruckcsw tottruckccan tottruckcfw tottruckcfp tottruckcbar
              railcostsw railcostcan railcostfw railcostfp railcostbar
              basiscostsw basiscostcan basiscostfp basiscostbar
              swcmemory
              fwcmemory
              edsw edcan edfw edfp edbar
              var1 var2 var3
              ucopsw ucopbar ucopcan ucopfp ucopfw
              copsw copbar copcan copfp copfw
              exppsw exppbar exppcan exppfp exppfw
              OFCsw OFCbar OFCfp OFCcan OFCfw
]

cplants-own [distvc distpr distch disttb distbd
              storcan
              basiscan
              VCcanqty TBcanqty CHcanqty BDcanqty
              canrailcVC canrailcTB canrailcBD
              cantotrcost
              ofcostcan
              railmargincan
]


eps-own [epstorfw
         distVC
         ethproduct
         dom-ethsupply
         exp-ethsupply
         ethrailc
         ethtotrcost
         nsgd
         tded
         ofcostfw
         ]
bds-own [distvc
         canrailcvc
         cantotrcost
         ofcostcan
         bdproduct
         dom-Biodsupply
         exp-Biodsupply]

cargills-own [
              gestorsw gestorbar gestorfp storcan
              basissw basisbar basisfp  basiscan
              nclosege
              distvc distpr distch disttb
              domswqty dombarqty domcanqty domfpqty


              VCswqty TBswqty VCbarqty TBbarqty
              VCcanqty TBcanqty VCfpqty TBfpqty
              railmarginsw railmarginbar railmarginfp railmargincan
              rv1 rv2
              swrailcVC swrailcTB swrailcCH
              barrailcVC barrailcTB barrailcCH
              fprailcVC fprailcTB fprailcCH
              canrailcVC canrailcTB canrailcCH
              swtotrcost bartotrcost cantotrcost fptotrcost
              ofcostsw ofcostbar ofcostfp ofcostcan
               ]
```

```
louisds-own [
             gestorsw gestorbar gestorfp storcan
             basissw basisbar basisfp  basiscan
             nclosege
             distvc distpr distch disttb
             domswqty dombarqty domcanqty domfpqty


             VCswqty TBswqty VCbarqty TBbarqty
             VCcanqty TBcanqty VCfpqty TBfpqty
             railmarginsw railmarginbar railmarginfp railmargincan
             rv1 rv2
             swrailcVC swrailcTB swrailcCH
             barrailcVC barrailcTB barrailcCH
             fprailcVC fprailcTB fprailcCH
             canrailcVC canrailcTB canrailcCH
             swtotrcost bartotrcost cantotrcost fptotrcost
             ofcostsw ofcostbar ofcostfp ofcostcan
              ]

pattersons-own [
             gestorsw gestorbar gestorfp storcan
             basissw basisbar basisfp  basiscan
             nclosege
             distvc distpr distch disttb
             domswqty dombarqty domcanqty domfpqty


             VCswqty TBswqty VCbarqty TBbarqty
             VCcanqty TBcanqty VCfpqty TBfpqty
             railmarginsw railmarginbar railmarginfp railmargincan
             rv1 rv2
             swrailcVC swrailcTB swrailcCH
             barrailcVC barrailcTB barrailcCH
             fprailcVC fprailcTB fprailcCH
             canrailcVC canrailcTB canrailcCH
             swtotrcost bartotrcost cantotrcost fptotrcost
             ofcostsw ofcostbar ofcostfp ofcostcan
              ]

pnhs-own [
             gestorsw gestorbar gestorfp storcan
             basissw basisbar basisfp  basiscan
             nclosege
             distvc distpr distch disttb
             domswqty dombarqty domcanqty domfpqty


             VCswqty TBswqty VCbarqty TBbarqty
             VCcanqty TBcanqty VCfpqty TBfpqty
             railmarginsw railmarginbar railmarginfp railmargincan
             rv1 rv2
             swrailcVC swrailcTB swrailcCH
             barrailcVC barrailcTB barrailcCH
             fprailcVC fprailcTB fprailcCH
             canrailcVC canrailcTB canrailcCH
             swtotrcost bartotrcost cantotrcost fptotrcost
             ofcostsw ofcostbar ofcostfp ofcostcan
              ]

richardsons-own [
             gestorsw gestorbar gestorfp storcan
             basissw basisbar basisfp  basiscan
```

```
              nclosege
              distvc distpr distch disttb
              domswqty dombarqty domcanqty domfpqty


              VCswqty TBswqty VCbarqty TBbarqty
              VCcanqty TBcanqty VCfpqty TBfpqty
              railmarginsw railmarginbar railmarginfp railmargincan
              rv1 rv2
              swrailcVC swrailcTB swrailcCH
              barrailcVC barrailcTB barrailcCH
              fprailcVC fprailcTB fprailcCH
              canrailcVC canrailcTB canrailcCH
              swtotrcost bartotrcost cantotrcost fptotrcost
              ofcostsw ofcostbar ofcostfp ofcostcan
               ]

viterras-own [
              gestorsw gestorbar gestorfp storcan
              basissw basisbar basisfp  basiscan
              nclosege
              distvc distpr distch disttb
              domswqty dombarqty domcanqty domfpqty


              VCswqty TBswqty VCbarqty TBbarqty
              VCcanqty TBcanqty VCfpqty TBfpqty
              railmarginsw railmarginbar railmarginfp railmargincan
              rv1 rv2
              swrailcVC swrailcTB swrailcCH
              barrailcVC barrailcTB barrailcCH
              fprailcVC fprailcTB fprailcCH
              canrailcVC canrailcTB canrailcCH
              swtotrcost bartotrcost cantotrcost fptotrcost
              ofcostsw ofcostbar ofcostfp ofcostcan
               ]

otherges-own [
              gestorsw gestorbar gestorfp storcan
              basissw basisbar basisfp  basiscan
              nclosege
              distvc distpr distch disttb
              domswqty dombarqty domcanqty domfpqty


              VCswqty TBswqty VCbarqty TBbarqty
              VCcanqty TBcanqty VCfpqty TBfpqty
              railmarginsw railmarginbar railmarginfp railmargincan
              rv1 rv2
              swrailcVC swrailcTB swrailcCH
              barrailcVC barrailcTB barrailcCH
              fprailcVC fprailcTB fprailcCH
              canrailcVC canrailcTB canrailcCH
              swtotrcost bartotrcost cantotrcost fptotrcost
              ofcostsw ofcostbar ofcostfp ofcostcan
               ]


;;;;;;;;;;;;;;;;;;;;;;; TO SETUP THE MODEL ;;;;;;;;;;;;;;;;;;;;;;;

to setup
  load-world
  crtagents
```

```
  ;patch-info
  ;farm-info

end


to Load-world
random-seed rand-seed
clear-everthing
load-gis
assign-yields-n-costs
assign-packages
load-prices
set-year

end

to clr-reset
  clear-turtles
  clear-patches
  clear-drawing
  clear-all-plots
  reset-ticks
end

to reset
random-seed rand-seed
clr-reset
load-gis
assign-yields-n-costs
assign-packages
load-prices
set-year
crtagents
end

to clear-everthing
  clear-turtles
  clear-patches
  clear-drawing
  clear-all-plots
  clear-output
  ca
end

to load-gis
 Ask Patches [
   set pcolor white]

;;;;;;;;;;;;;;;;;;;load esri shp files into netlogo ;;;;;;;;;;;;;;;;;;

  gis:load-coordinate-system "data/NewSkcar/skcar.prj"
  set skcar-dataset gis:load-dataset "data/NewSkcar/june28skcar.shp"
  set sksoil-dataset gis:load-dataset "data/Sksoil/Sksoil2.shp"
  set cargill-dataset gis:load-dataset
"data/NewGES/IndividualGES/cargill.shp"
  set louisd-dataset gis:load-dataset "data/NewGES/IndividualGES/louisd.shp"
  set patterson-dataset gis:load-dataset "data/NewGES/IndividualGES/pat.shp"
  set pnh-dataset gis:load-dataset "data/NewGES/IndividualGES/pnh.shp"
  set richardson-dataset gis:load-dataset
"data/NewGES/IndividualGES/rich.shp"
  set viterra-dataset gis:load-dataset
"data/NewGES/IndividualGES/viterra.shp"
```

```
  set otherges-dataset gis:load-dataset
"data/NewGES/IndividualGES/otherge.shp"
  set cp-dataset gis:load-dataset "data/Biodiesel/crushplant.shp"
  set bd-dataset gis:load-dataset "data/Biodiesel/Biodieselplant.shp"
  set ep-dataset gis:load-dataset "data/EPS/EPS1.shp"


  gis:set-world-envelope gis:envelope-of skcar-dataset
  set realworld-width 631.6     ;; width of world in km, determined from
calculating the geodesic distance on ArcGIS
  set realworld-height 631.3    ;; height of world in km, see above

;; factor = GIS units per netlogo unit
  set xfactor realworld-width / world-width
  set yfactor realworld-height / world-height


 ;ask netlogo to draw CAR boundaries
 gis:set-drawing-color black
 gis:draw skcar-dataset 1



;Load road network
;gis:set-drawing-color blue - 2
;gis:draw roa-dataset 0.5

;load soil zones
;gis:set-drawing-color grey
;gis:draw sksoil-dataset 0.1

;load rail network
;gis:set-drawing-color grey
;gis:draw rla-dataset 2

;load town network
; gis:set-drawing-color black
; gis:draw town-dataset 1
end


to assign-yields-n-costs

; yields to patches
foreach gis:feature-list-of sksoil-dataset[
ask patches gis:intersecting ?[
  set zone (gis:property-value ? "ZONE_1")
  set land-id (gis:property-value ? "AREA")
  set ysw (gis:property-value ? "YLDWHT") * 0.001 / 2.47105381 * 1.5
  set ycan (gis:property-value ? "YLDCAN") * 0.001 / 2.47105381 * 2
  set yfw (gis:property-value ? "YLDWHT") * 0.001 / 2.47105381 * 1.5 * 1.07
; Industrial Wheat has a higher yield than traditional wheat (Crop Planning
Guide 2011)
 ;set yfp ycan * 1.423845068
; Field peas yield has historically been 1.4 times the yield of canola
(Statistics Canada)
  set ybar (gis:property-value ? "YLDBAR") * 0.001 / 2.47105381 * 0.75



  set swfuel (gis:property-value ? "SWFUELCOST")
  set swfert (gis:property-value ? "SWFERT_COS")
  set swTVC (gis:property-value ? "SWTOTVAR_E")
```

```
  set barfuel (gis:property-value ? "BARFUELCOS")
  set barfert (gis:property-value ? "BARFERT_CO")
  set barTVC (gis:property-value ? "BARTOTVAR_")

  set canfuel (gis:property-value ? "CANFUELCOS")
  set canfert (gis:property-value ? "CANFERT_CO")
  set canTVC (gis:property-value ? "CANTOTVAR_")

  set fpfuel (gis:property-value ? "FPFUELCOST")
  set fpfert (gis:property-value ? "FPFERT_COS")
  set fpTVC (gis:property-value ? "FPTOTVAR_E")

  set fwfuel swfuel
  set fwfert swfert
  set fwTVC swTVC
]]

;if yields = 0 for current location set yields to average yield based soil
zone obtained from Crop Planner
ask patches[
  if ysw = 0
  [if zone = "BROWN"
    [set ysw 29.8 * 0.027216]
   if zone = "DARK BROWN"
    [set ysw 34.2 * 0.027216]
   if zone = "BLACK"
    [set ysw 41.8 * 0.027216]]

  if ycan = 0
  [if zone = "BROWN"
    [set ycan 23.2 * 0.022680]
   if zone = "DARK BROWN"
    [set ycan 33.1 * 0.022680]
   if zone = "BLACK"
    [set ycan 36.7 * 0.022680]]

  if yfw = 0
  [if zone = "BROWN"
    [set yfw 32.8 * 0.027216]
   if zone = "DARK BROWN"
    [set yfw 41.8 * 0.027216]
   if zone = "BLACK"
    [set yfw 51.4 * 0.027216]]

  if yfp = 0
  [if zone = "BROWN"
    [set yfp 31.6 * 0.027216]
   if zone = "DARK BROWN"
    [set yfp 36.9 * 0.027216]
   if zone = "BLACK"
    [set yfp 37.2 * 0.027216]]

  if ybar = 0
  [if zone = "BROWN"
    [set ybar 48.6 * 0.021772]
   if zone = "DARK BROWN"
    [set ybar 61.3 * 0.021772]
   if zone = "BLACK"
    [set ybar 70.6 * 0.021772]]
]
end
```

```
to assign-packages
;assign packages to patches
foreach gis:feature-list-of skcar-dataset[
ask patches gis:intersecting ?[
  set cid gis:property-value ? "CAR"
  set mwmbw gis:property-value ? "MWMBW"
  set mwmbc gis:property-value ? "MWMBCAN"
  set mwmbb gis:property-value ? "MWMBBAR"
  set mwmbf gis:property-value ? "MWMBFP"
  set mwmfw gis:property-value ? "MWMFW"
  set mwmfc gis:property-value ? "MWMFCAN"
  set mwmfb gis:property-value ? "MWMFBAR"
  set mwmff gis:property-value ? "MWMFFP"
  set mcmbw gis:property-value ? "MCMBW"
  set mcmbc gis:property-value ? "MCMBCAN"
  set mcmbb gis:property-value ? "MCMBBAR"
  set mcmbf gis:property-value ? "MCMBFP"
  set mcmfw gis:property-value ? "MCMFW"
  set mcmfc gis:property-value ? "MCMFCAN"
  set mcmfb gis:property-value ? "MCMFBAR"
  set mcmff gis:property-value ? "MCMFFP"
  ]]
end

;;;;;;;;;;;;;;;;;;;;;;;;;;;; LOAD PRICE LIST ;;;;;;;;;;;;;;;;;;;;;;;;;;;

to load-prices

file-open (word "data/textfiles/timePaths/Wheat Time Path/wtp" TimePath
".txt")
set wpswlist file-read
file-close

file-open (word "data/textfiles/timePaths/Barley Time Path/btp" TimePath
".txt")
set wpbarlist file-read
file-close

file-open (word "data/textfiles/timePaths/Canola Time Path/ctp" TimePath
".txt")
set wpcanlist file-read
file-close

file-open (word "data/textfiles/timePaths/Field Pea Time Path/ftp" TimePath
".txt")
set wpfplist file-read
file-close
end



;;;;;;;;;;;;;;;;;;;;;;;;;;;;;; set the Year;;;;;;;;;;;;;;;;

to set-year
set year 2010
end


to patch-info
ask patches with [cid != 0 and land-id != 0][set pcolor brown + 3]
ask patches with [cid != 0 and land-id = 0][set pcolor blue + 3]
ask patches with [cid = 0][set pcolor black]
show "Number of Patches in the Model:" show count(patches with [cid != 0 and
land-id != 0])
```

```
set patches-in-model (patch-set patches with [cid != 0 and land-id != 0])
show "Number of Patches in Water:"  show count(patches with [cid != 0 and
land-id = 0])
show "Number of Patches in CAR:" show count(patches with [cid != 0])
Show "Number of Acres per Patch:" show  210358335 / count(patches with [cid
!= 0])
end

to crtagents
  crtfarmers
  crtges
  crteps
  crtcps
  crtbd
end


to crtfarmers
Ask n-of 1501 patches with [cid = "1a" and land-id != 0]
[sprout-farmers 1
  [set shape "person"
   set color blue
   set swy ([ysw] of patch-here)
   set cany ([ycan] of patch-here)
   set fwy ([yfw] of patch-here)
   set fpy ([yfp] of patch-here)
   set bary ([ybar] of patch-here)
    ]]


Ask n-of 1496 patches with [cid = "1b"and land-id != 0]
[sprout-farmers 1
  [set shape "person"
   set color blue
   set swy ([ysw] of patch-here)
   set cany ([ycan] of patch-here)
   set fwy ([yfw] of patch-here)
   set fpy ([yfp] of patch-here)
   set bary ([ybar] of patch-here)
   ]]


Ask n-of 1094 patches with [cid = "2a"and land-id != 0]
[sprout-farmers 1
  [set shape "person"
   set color blue
   set swy ([ysw] of patch-here)
   set cany ([ycan] of patch-here)
   set fwy ([yfw] of patch-here)
   set fpy ([yfp] of patch-here)
   set bary ([ybar] of patch-here)
   ]]


Ask n-of 2018 patches with [cid = "2b"and land-id != 0]
[sprout-farmers 1
  [set shape "person"
   set color blue
   set swy ([ysw] of patch-here)
   set cany ([ycan] of patch-here)
   set fwy ([yfw] of patch-here)
   set fpy ([yfp] of patch-here)
   set bary ([ybar] of patch-here)
   ]]
```

```
Ask n-of 955 patches with [cid = "3an"and land-id != 0]
[sprout-farmers 1
  [set shape "person"
   set color blue
   set swy ([ysw] of patch-here)
   set cany ([ycan] of patch-here)
   set fwy ([yfw] of patch-here)
   set fpy ([yfp] of patch-here)
   set bary ([ybar] of patch-here)
   ]]


Ask n-of 1758 patches with [cid = "3as"and land-id != 0]
[sprout-farmers 1
  [set shape "person"
   set color blue
   set swy ([ysw] of patch-here)
   set cany ([ycan] of patch-here)
   set fwy ([yfw] of patch-here)
   set fpy ([yfp] of patch-here)
   set bary ([ybar] of patch-here)
   ]]


Ask n-of 1864 patches with [cid = "3bn"and land-id != 0]
[sprout-farmers 1
  [set shape "person"
   set color blue
   set swy ([ysw] of patch-here)
   set cany ([ycan] of patch-here)
   set fwy ([yfw] of patch-here)
   set fpy ([yfp] of patch-here)
   set bary ([ybar] of patch-here)
   ]]


Ask n-of 1050 patches with [cid = "3bs"and land-id != 0]
[sprout-farmers 1
  [set shape "person"
   set color blue
   set swy ([ysw] of patch-here)
   set cany ([ycan] of patch-here)
   set fwy ([yfw] of patch-here)
   set fpy ([yfp] of patch-here)
   set bary ([ybar] of patch-here)
   ]]


Ask n-of 859 patches with [cid = "4a"and land-id != 0]
[sprout-farmers 1
  [set shape "person"
   set color blue
   set swy ([ysw] of patch-here)
   set cany ([ycan] of patch-here)
   set fwy ([yfw] of patch-here)
   set fpy ([yfp] of patch-here)
   set bary ([ybar] of patch-here)
   ]]


Ask n-of 910 patches with [cid = "4b"and land-id != 0]
[sprout-farmers 1
```

```
  [set shape "person"
   set color blue
   set swy ([ysw] of patch-here)
   set cany ([ycan] of patch-here)
   set fwy ([yfw] of patch-here)
   set fpy ([yfp] of patch-here)
   set bary ([ybar] of patch-here)
   ]]


Ask n-of 2893 patches with [cid = "5a"and land-id != 0]
[sprout-farmers 1
  [set shape "person"
   set color blue
   set swy ([ysw] of patch-here)
   set cany ([ycan] of patch-here)
   set fwy ([yfw] of patch-here)
   set fpy ([yfp] of patch-here)
   set bary ([ybar] of patch-here)
   ]]

Ask n-of 2965 patches with [cid = "5b"and land-id != 0]
[sprout-farmers 1
  [set shape "person"
   set color blue
   set swy ([ysw] of patch-here)
   set cany ([ycan] of patch-here)
   set fwy ([yfw] of patch-here)
   set fpy ([yfp] of patch-here)
   set bary ([ybar] of patch-here)
   ]]


Ask n-of 2575 patches with [cid = "6a"and land-id != 0]
[sprout-farmers 1
  [set shape "person"
   set color blue
   set swy ([ysw] of patch-here)
   set cany ([ycan] of patch-here)
   set fwy ([yfw] of patch-here)
   set fpy ([yfp] of patch-here)
   set bary ([ybar] of patch-here)
   ]]


Ask n-of 2616 patches with [cid = "6b"and land-id != 0]
[sprout-farmers 1
 [set shape "person"
   set color blue
   set swy ([ysw] of patch-here)
   set cany ([ycan] of patch-here)
   set fwy ([yfw] of patch-here)
   set fpy ([yfp] of patch-here)
   set bary ([ybar] of patch-here)
   ]]


Ask n-of 1412 patches with [cid = "7a"and land-id != 0]
[sprout-farmers 1
  [set shape "person"
   set color blue
   set swy ([ysw] of patch-here)
   set cany ([ycan] of patch-here)
   set fwy ([yfw] of patch-here)
```

```
    set fpy ([yfp] of patch-here)
    set bary ([ybar] of patch-here)
    ]]


Ask n-of 1428 patches with [cid = "7b"and land-id != 0]
[sprout-farmers 1
  [set shape "person"
   set color blue
   set swy ([ysw] of patch-here)
   set cany ([ycan] of patch-here)
   set fwy ([yfw] of patch-here)
   set fpy ([yfp] of patch-here)
   set bary ([ybar] of patch-here)
   ]]


Ask n-of 1920 patches with [cid = "8a"and land-id != 0]
[sprout-farmers 1
  [set shape "person"
   set color blue
   set swy ([ysw] of patch-here)
   set cany ([ycan] of patch-here)
   set fwy ([yfw] of patch-here)
   set fpy ([yfp] of patch-here)
   set bary ([ybar] of patch-here)
   ]]


Ask n-of 1899 patches with [cid = "8b"and land-id != 0]
[sprout-farmers 1
  [set shape "person"
   set color blue
   set swy ([ysw] of patch-here)
   set cany ([ycan] of patch-here)
   set fwy ([yfw] of patch-here)
   set fpy ([yfp] of patch-here)
   set bary ([ybar] of patch-here)
   ]]

Ask n-of 3276 patches with [cid = "9a"and land-id != 0]
[sprout-farmers 1
  [set shape "person"
   set color blue
   set swy ([ysw] of patch-here)
   set cany ([ycan] of patch-here)
   set fwy ([yfw] of patch-here)
   set fpy ([yfp] of patch-here)
   set bary ([ybar] of patch-here)
   ]]


Ask n-of 2463 patches with [cid = "9b"and land-id != 0]
[sprout-farmers 1
   [set shape "person"
   set color blue
   set swy ([ysw] of patch-here)
   set cany ([ycan] of patch-here)
   set fwy ([yfw] of patch-here)
   set fpy ([yfp] of patch-here)
   set bary ([ybar] of patch-here)
   ]]
```

```
file-open "data/textfiles/Landsize/june28Landsize.txt"
set landlist file-read
file-close
foreach sort farmers[
  ask ? [set land first landlist
         set landlist but-first landlist]]


file-open "data/textfiles/Degree of Responsiveness/DORjune28.txt"
set discfactlist file-read
file-close

foreach sort farmers[
  ask ? [set discfact first discfactlist
         set discfactlist but-first discfactlist]]

end

to farm-info
show "Number of farmers in the model:" show count(farmers)
show "Total Crop-land acreage:" show sum([land] of farmers)

end



;;;;;;;;;;;;;;;;;;;;;;;;; Create Grain Elevators ;;;;;;;;;;;;;;;;;;;;;;;;;

to crtges
foreach gis:feature-list-of cargill-dataset
[ask patches gis:intersecting ?
 [sprout-cargills 1

  [set shape "house"
    set color red
   set size 10
  set distVC gis:property-value ? "DISTANCEVC"
  set distpr gis:property-value ? "DISTANCEPR"
  set distch gis:property-value ? "DISTANCECH"
  set disttb gis:property-value ? "DISTANCETB"   ]]]

foreach gis:feature-list-of louisd-dataset
[ask patches gis:intersecting ?
 [sprout-louisds 1

  [set shape "house"
    set color red
   set size 10
  set distVC gis:property-value ? "DISTANCEVC"
  set distpr gis:property-value ? "DISTANCEPR"
  set distch gis:property-value ? "DISTANCECH"
  set disttb gis:property-value ? "DISTANCETB"   ]]]

foreach gis:feature-list-of patterson-dataset
[ask patches gis:intersecting ?
 [sprout-pattersons 1

  [set shape "house"
   set color red
   set size 10
   set distVC gis:property-value ? "DISTANCEVC"
   set distpr gis:property-value ? "DISTANCEPR"
   set distch gis:property-value ? "DISTANCECH"
```

```
   set disttb gis:property-value ? "DISTANCETB"   ]]]

foreach gis:feature-list-of pnh-dataset
[ask patches gis:intersecting ?
 [sprout-pnhs 1

  [set shape "house"
    set color red
   set size 10
  set distVC gis:property-value ? "DISTANCEVC"
  set distpr gis:property-value ? "DISTANCEPR"
  set distch gis:property-value ? "DISTANCECH"
  set disttb gis:property-value ? "DISTANCETB"   ]]]

foreach gis:feature-list-of richardson-dataset
[ask patches gis:intersecting ?
 [sprout-richardsons 1

  [set shape "house"
    set color red
   set size 10
  set distVC gis:property-value ? "DISTANCEVC"
  set distpr gis:property-value ? "DISTANCEPR"
  set distch gis:property-value ? "DISTANCECH"
  set disttb gis:property-value ? "DISTANCETB"   ]]]

foreach gis:feature-list-of viterra-dataset
[ask patches gis:intersecting ?
 [sprout-viterras 1

  [set shape "house"
    set color red
   set size 10
  set distVC gis:property-value ? "DISTANCEVC"
  set distpr gis:property-value ? "DISTANCEPR"
  set distch gis:property-value ? "DISTANCECH"
  set disttb gis:property-value ? "DISTANCETB"   ]]]

foreach gis:feature-list-of otherges-dataset
[ask patches gis:intersecting ?
 [sprout-otherges 1

  [set shape "house"
    set color red
   set size 10
  set distVC gis:property-value ? "DISTANCEVC"
  set distpr gis:property-value ? "DISTANCEPR"
  set distch gis:property-value ? "DISTANCECH"
  set disttb gis:property-value ? "DISTANCETB"   ]]]

set all-ges (turtle-set cargills louisds pattersons pnhs richardsons viterras
otherges)

end


to crteps
foreach gis:feature-list-of ep-dataset
[ask patches gis:intersecting ?
[sprout-eps 1
  [set shape "house"
   set color yellow
   set size 15
   set distVC gis:property-value ? "DISTVC"]]]
```

```
end

to crtcps
foreach gis:feature-list-of cp-dataset
[ask patches gis:intersecting ?
[sprout-cplants 1
  [set shape "house"
    set color green
   set size 13
  set distVC gis:property-value ? "DISTANCEVC"
  set distpr gis:property-value ? "DISTANCEPR"
  set distch gis:property-value ? "DISTANCECH"
  set disttb gis:property-value ? "DISTANCETB"
  set distBD gis:property-value ? "DIST_BioD_"]]]

set grainhandlers (turtle-set cplants all-ges)
end

to crtbd
foreach gis:feature-list-of bd-dataset
[ask patches gis:intersecting ?
[sprout-bds 1
  [set shape "circle"
    set color violet
   set size 15
   set distvc 1406.790765]]]

end



;;;;;;;;;;;;;;;;;;;;;;;;;;; Get World Prices  ;;;;;;;;;;;;;;;;;;;;;;;;;;;

to set-world-prices
ifelse ticks <= 4
[set year 2010]
[set year year + 1]



;SPRING WHEAT
set wpsw first wpswlist
set wpswlist but-first wpswlist
;BARLEY
set wpbar first wpbarlist
set wpbarlist but-first wpbarlist
;CANOLA
set wpcan first wpcanlist
set wpcanlist but-first wpcanlist
;FIELD PEAS
set wpfp first wpfplist
set wpfplist but-first wpfplist

Ifelse ticks = 0
[set crude-price 82.88
 set pfwt 0]
; Real Average North American Crude Oil Price for January 2010 Canadian
$/barrel
[set crude-price crude-price * (1 + (doil-price / 100))]
end


;;;;;;;;;;;;;;;;;;;;;;;;;; ASK FARMERS TO PRODUCE ;;;;;;;;;;;;;;;;;;;;;;;;;;
```

```
to produce
  farm
  store
  cmpt-cop
 ; show "Production Complete"
end

to farm
  getprice
  allocate-acreage
  plant
end



to getprice


ifelse ticks = 0
  [ask farmers
   [set exppsw  wpsw * swy
    set exppbar wpbar * bary
    set exppcan wpcan * cany
    set exppfp wpfp * fpy
    set exppfw pfwt * fwy]]
  [ask farmers
   [set exppsw (fgpsw * (1 - discfact) + (discfact) * (wpsw - vcsw)) * swy
    set exppfw (fgpfw *(1 - discfact) + (discfact) * (pfwt - vcfw)) * fwy
    set exppbar (fgpbar * (1 - discfact) + (discfact) * (wpbar - vcbar)) *
bary
    set exppcan (fgpcan * (1 - discfact) + (discfact) * (wpcan - vccan)) *
cany
    set exppfp (fgpfp * (1 - discfact) + (discfact) * (wpfp - vcfp)) * fpy
    ]]


  end




to allocate-acreage
ifelse bio-ethanol
[ask farmers
  [ifelse exppsw > exppfw
   [ifelse exppsw > exppcan and exppbar > exppfp
    [SWpackage1]
    [ifelse exppsw > exppcan and exppbar < exppfp
     [SWpackage2]
     [ifelse exppsw < exppcan and exppbar > exppfp
      [SWpackage3]
      [SWpackage4]]]]
   [ifelse exppsw > exppcan and exppbar > exppfp
    [FWpackage1]
    [ifelse exppsw > exppcan and exppbar < exppfp
     [FWpackage2]
     [ifelse exppsw < exppcan and exppbar > exppfp
      [FWpackage3]
      [FWpackage4]]]]]]

[ask farmers
  [ifelse exppsw > exppcan and exppbar > exppfp
   [SWpackage1]
   [ifelse exppsw > exppcan and exppbar < exppfp
```

```
    [SWpackage2]
    [ifelse exppsw < exppcan and exppbar > exppfp
     [SWpackage3]
     [SWpackage4]]]]]

end

to SWpackage1
set swr [mwmbw] of patch-here
set canr [mwmbc] of patch-here
set barr [mwmbb] of patch-here
set fpr [mwmbf] of patch-here
set fwr 0
end
to SWpackage2
set swr [mwmfw] of patch-here
set canr [mwmfc] of patch-here
set barr [mwmfb] of patch-here
set fpr [mwmff] of patch-here
set fwr 0
end
to SWpackage3
set swr [mcmbw] of patch-here
set canr [mcmbc] of patch-here
set barr [mcmbb] of patch-here
set fpr [mcmbf] of patch-here
set fwr 0
end
to SWpackage4
set swr [mcmfw] of patch-here
set canr [mcmfc] of patch-here
set barr [mcmfb] of patch-here
set fpr [mcmff] of patch-here
set fwr 0
end


to FWpackage1
set fwr [mwmbw] of patch-here
set canr [mwmbc] of patch-here
set barr [mwmbb] of patch-here
set fpr [mwmbf] of patch-here
set swr 0
end
to FWpackage2
set fwr [mwmfw] of patch-here
set canr [mwmfc] of patch-here
set barr [mwmfb] of patch-here
set fpr [mwmff] of patch-here
set swr 0
end
to FWpackage3
set fwr [mcmbw] of patch-here
set canr [mcmbc] of patch-here
set barr [mcmbb] of patch-here
set fpr [mcmbf] of patch-here
set swr 0
end
to FWpackage4
set Fwr [mcmfw] of patch-here
set canr [mcmfc] of patch-here
set barr [mcmfb] of patch-here
set fpr [mcmff] of patch-here
set swr 0
```

```
end



to plant
  ask farmers[
    set swa swr * land
    set cana canr * land
    set fwa fwr * land
    set fpa fpr * land
    set bara barr * land
  ]
end

 to store
   ask farmers[
     set fstorsw round(swy * swa)
     set fstorcan round(cany * cana)
     set fstorfw round(fwy * fwa)
     set fstorfp round(fpy * fpa )
     set fstorbar round(bary * bara)
   ]


 set fwithsw (farmers with [fstorsw > 0])
 set fwithbar (farmers with [fstorbar > 0])
 set fwithfp (farmers with [fstorfp > 0])
 set fwithcan (farmers with [fstorcan > 0])
 set fwithfw (farmers with [fstorfw > 0])

 set fw/osw (farmers with [fstorsw = 0])
 set fw/obar (farmers with [fstorbar = 0])
 set fw/ofp (farmers with [fstorfp = 0])
 set fw/ocan (farmers with [fstorcan = 0])
 set fw/ofw (farmers with [fstorfw = 0])


 set total-sw-production sum([fstorsw] of farmers)
 set total-can-production sum([fstorcan] of farmers)
 set total-fw-production sum([fstorfw] of farmers)
 set total-fp-production sum([fstorfp] of farmers)
 set total-bar-production sum([fstorbar] of farmers)
 end



;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;; Compute COP ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

to cmpt-cop
ifelse ticks = 0
[ask farmers[
  set ucopsw ([swTVC]of patch-here )
  set ucopcan ([canTVC]of patch-here)
  set ucopbar ([barTVC]of patch-here)
  set ucopfp ([fpTVC]of patch-here)
  set ucopfw ([fwTVC]of patch-here)

  set copsw ucopsw * swa
  set copcan ucopcan * cana
  set copbar ucopbar * bara
  set copfp ucopfp * fpa
  set copfw ucopfw * fwa]]
```

```
[ask farmers[
  set ucopsw ucopsw + (([swfuel]of patch-here * (0.75 * (doil-price / 100)))
+ ([swfert]of patch-here * (0.33 * (doil-price / 100))))
  set ucopcan ucopcan + (([canfuel]of patch-here *  (0.75 * (doil-price /
100))) + ([canfert]of patch-here * (0.33 * (doil-price / 100))))
  set ucopbar ucopbar + (([barfuel]of patch-here * (0.75 * (doil-price /
100))) + ([barfert]of patch-here * (0.33 * (doil-price / 100))))
  set ucopfp ucopfp + (([fpfuel]of patch-here * (0.75 * (doil-price / 100)))
+ ([fpfert]of patch-here * (0.33 * (doil-price / 100))))
  set ucopfw ucopfw + (([fwfuel]of patch-here * (0.75 * (doil-price / 100)))
+ ([fwfert]of patch-here * (0.33 * (doil-price / 100))))

  set copsw ucopsw * swa
  set copcan ucopcan * cana
  set copbar ucopbar * bara
  set copfp ucopfp * fpa
  set copfw ucopfw * fwa]]
; Fuel Elasticity Chacra 2002, Fertilizer Elasticity Baffes 2007

end



;;;;;;;;;;;;;;;;;;;;;;;; Farmers Ship Grain ;;;;;;;;;;;;;;;;;;;;;;;;;;

 to srchntruck
   cmpt-gebasis
   gesearch
   truck
   calc-truck-cost
;   show "Trucking Complete"
 end

to cmpt-gebasis ;grain elevators set their prices
; Have GEs set dockage and storage fees as some random function of the
maximum tariffs set by the elevator co. & the number of GEs in close
proximity
  ifelse year = 2010
  [ask cargills[
  set nclosege (count (all-ges in-radius (close / yfactor) ) - 1)
  ifelse nclosege = 0
  [set basissw CAmaxtariffsw
   set basisbar CAmaxtariffbar
   set basisfp CAmaxtariffp
   set basiscan CAmaxtariffcan]

   [set basissw CAmaxtariffsw - ( 1 + random nclosege)
    set basisbar CAmaxtariffbar - ( 1 + random nclosege)
    set basisfp CAmaxtariffp - ( 1 + random nclosege)
    set basiscan CAmaxtariffcan - ( 1 + random nclosege)]]

  ask louisds[
  set nclosege (count (all-ges in-radius (close / yfactor) ) - 1)
  ifelse nclosege = 0
  [set basissw LDmaxtariffsw
   set basisbar LDmaxtariffbar
   set basisfp LDmaxtariffp
   set basiscan LDmaxtariffcan]

   [set basissw LDmaxtariffsw - ( 1 + random nclosege)
    set basisbar LDmaxtariffbar - ( 1 + random nclosege)
    set basisfp LDmaxtariffp - ( 1 + random nclosege)
    set basiscan LDmaxtariffcan - ( 1 + random nclosege)]]
```

```
ask pattersons[
set nclosege (count (all-ges in-radius (close / yfactor) ) - 1)
ifelse nclosege = 0
[set basissw PAmaxtariffsw
 set basisbar PAmaxtariffbar
 set basisfp PAmaxtariffp
 set basiscan PAmaxtariffcan]

 [set basissw PAmaxtariffsw - ( 1 + random nclosege)
  set basisbar PAmaxtariffbar - ( 1 + random nclosege)
  set basisfp PAmaxtariffp - ( 1 + random nclosege)
  set basiscan PAmaxtariffcan - ( 1 + random nclosege)]]

ask pnhs[
set nclosege (count (all-ges in-radius (close / yfactor) ) - 1)
ifelse nclosege = 0
[set basissw PHmaxtariffsw
 set basisbar PHmaxtariffbar
 set basisfp PHmaxtariffp
 set basiscan PHmaxtariffcan]

 [set basissw PHmaxtariffsw - ( 1 + random nclosege)
  set basisbar PHmaxtariffbar - ( 1 + random nclosege)
  set basisfp PHmaxtariffp - ( 1 + random nclosege)
  set basiscan PHmaxtariffcan - ( 1 + random nclosege)]]

 ask richardsons[
set nclosege (count (all-ges in-radius (close / yfactor) ) - 1)
ifelse nclosege = 0
[set basissw RDmaxtariffsw
 set basisbar RDmaxtariffbar
 set basisfp RDmaxtariffp
 set basiscan RDmaxtariffcan]

 [set basissw RDmaxtariffsw - ( 1 + random nclosege)
  set basisbar RDmaxtariffbar - ( 1 + random nclosege)
  set basisfp RDmaxtariffp - ( 1 + random nclosege)
  set basiscan RDmaxtariffcan - ( 1 + random nclosege)]]

ask viterras[
set nclosege (count (all-ges in-radius (close / yfactor) ) - 1)
ifelse nclosege = 0
[set basissw VImaxtariffsw
 set basisbar VImaxtariffbar
 set basisfp VImaxtariffp
 set basiscan VImaxtariffcan]

 [set basissw VImaxtariffsw - ( 1 + random nclosege)
  set basisbar VImaxtariffbar - ( 1 + random nclosege)
  set basisfp VImaxtariffp - ( 1 + random nclosege)
  set basiscan VImaxtariffcan - ( 1 + random nclosege)]]

ask otherges[
set nclosege (count (all-ges in-radius (close / yfactor) ) - 1)
ifelse nclosege = 0
[set basissw OTmaxtariffsw
 set basisbar OTmaxtariffbar
 set basisfp OTmaxtariffp
 set basiscan OTmaxtariffcan]

 [set basissw OTmaxtariffsw - ( 1 + random nclosege)
  set basisbar OTmaxtariffbar - ( 1 + random nclosege)
  set basisfp OTmaxtariffp - ( 1 + random nclosege)
  set basiscan OTmaxtariffcan - ( 1 + random nclosege)]
```

```
   ask cplants[
     set basiscan sum([basiscan] of all-ges)/ count all-ges + 10 ]]]
; Crushing Plant basisis cost is the average of elevators' canola handling
fee plus a crushing margin of $10 per M.T.


 ; GE dies if the elevator basis price for all crops falls to zero
   [ask all-ges
    [ifelse (basissw <= 0 and basisbar <= 0 and basisfp = 0)
      [die]
      [; if the amt of ge crop storage is greater than average crop storage
of other elevators in close proximity: increase basis by random function of
number of elevators in close proximity, if less decrease, if equal remain the
same
       ifelse basissw = 0
        [set basissw 0]
        [ifelse gestorsw = 0
         [set basissw basissw - min(list random close basissw)]
         [ifelse gestorsw <  sum([gestorsw] of all-ges in-radius (close /
yfactor) )/ count(all-ges in-radius (close / yfactor))
          [set basissw basissw - min(list random close basissw)]
         [ifelse gestorsw  >  sum([gestorsw] of all-ges in-radius (close /
yfactor) )/ count(all-ges in-radius (close / yfactor))
          [set basissw basissw + random close]
          [set basissw basissw]]]]


       ifelse basisfp = 0
        [set basisfp 0]
        [ifelse gestorfp = 0
         [set basisfp basisfp - min(list random close basisfp)]
         [ifelse gestorfp <  sum([gestorfp] of all-ges in-radius (close /
yfactor) )/ count(all-ges in-radius (close / yfactor))
          [set basisfp basisfp - min(list random close basisfp)]
         [ifelse gestorfp >  sum([gestorfp] of all-ges in-radius (close /
yfactor) )/ count(all-ges in-radius (close / yfactor))
          [set basisfp basisfp + random close]
          [set basisfp basisfp]]]]



       ifelse basisbar = 0
        [set basisbar 0]
        [ifelse gestorbar = 0
         [set basisbar basisbar - min(list random close basisbar)]
         [ifelse  gestorbar  <  sum([gestorbar] of all-ges in-radius (close /
yfactor) )/ count(all-ges in-radius (close / yfactor))
          [set basisbar basisbar - min(list random close basisbar)]
         [ifelse gestorbar  >  sum([gestorbar] of all-ges in-radius (close /
yfactor) )/ count(all-ges in-radius (close / yfactor))
          [set basisbar basisbar + random close]
          [set basisbar basisbar]]]]


       ifelse basiscan = 0
        [set basiscan 0]
        [ifelse storcan = 0
         [set basiscan basiscan - min(list random close basiscan)]
         [ifelse  storcan  <  sum([storcan] of all-ges in-radius (close /
yfactor) )/ count(all-ges in-radius (close / yfactor))
          [set basiscan basiscan - min(list random close basiscan)]
         [ifelse storcan  >  sum([storcan] of all-ges in-radius (close /
yfactor) )/ count(all-ges in-radius (close / yfactor))
```

```
          [set basiscan basiscan + random close]
          [set basiscan basiscan]]]]]

     ask cplants[
     set basiscan sum([basiscan] of all-ges)/ count all-ges]

    ]]

 end



to gesearch ;farmers look for grain elevators the lowest trucking cost and
the lowest Storage and handling fees (tarrifs)

;SW
Ask farmers[
    set fgec-sw 0
    set var1 [who] of all-ges with [distance myself < (trucking-threshold /
yfactor)]
    ]
ask farmers[
  ifelse (count(all-ges with [distance myself < (trucking-threshold /
yfactor)]) <= 1 )
   [set fgec-sw min-one-of all-ges [distance myself]]

   [set fgec-sw min-one-of all-ges with [distance myself < (trucking-
threshold / yfactor)][basissw]]
]


;BARLEY
Ask farmers[
    set fgec-bar 0
    set var1 [who] of all-ges with [distance myself < (trucking-threshold /
yfactor)]]
ask farmers[
  ifelse (count(all-ges with [distance myself < (trucking-threshold /
yfactor)]) <= 1 )
   [set fgec-bar min-one-of all-ges [distance myself]]

   [set fgec-bar min-one-of all-ges with [distance myself < (trucking-
threshold / yfactor)][basisbar]]
]

;FIELD PEAS
Ask farmers[
    set fgec-fp 0
    set var1 [who] of all-ges with [distance myself < (trucking-threshold /
yfactor)]
    ]
ask farmers[
  ifelse (count(all-ges with [distance myself < (trucking-threshold /
yfactor)]) <= 1 )
   [set fgec-fp min-one-of all-ges [distance myself]]

   [set fgec-fp min-one-of all-ges with [distance myself < (trucking-
threshold / yfactor)][basisfp]]
]


;INDUSTRIAL WHEAT
  ask farmers[
    set fepc-fw min-one-of eps [distance myself]]
```

```
;CANOLA
  ask farmers[
    set fghc-can min-one-of grainhandlers [distance myself]]
end


to truck
 reset-vars
  ask farmers[
   ask fgec-sw[set gestorsw gestorsw + [fstorsw] of myself]
   ask fgec-bar[set gestorbar gestorbar + [fstorbar] of myself]
   ask fgec-fp[set gestorfp gestorfp + [fstorfp] of myself]
   ask fepc-fw[set epstorfw epstorfw + [fstorfw] of myself]
   ask fghc-can[set storcan storcan + [fstorcan] of myself]

   set basiscostsw [basissw] of fgec-sw * fstorsw
   set basiscostcan [basiscan] of fghc-can * fstorcan
   set basiscostbar [basisbar] of fgec-bar * fstorbar
   set basiscostfp [basisfp] of fgec-fp * fstorfp]


 set gewithsw (all-ges with [gestorsw > 0])
 set gewithbar (all-ges with [gestorbar > 0])
 set gewithfp (all-ges with [gestorfp > 0])
 set cpwithcan (cplants with [storcan > 0])
 set ghwithcan (grainhandlers with [storcan > 0])
 set epwithfw (eps with [epstorfw > 0])

 set gew/osw (all-ges with [gestorsw = 0])
 set gew/obar (all-ges with [gestorbar = 0])
 set gew/ofp (all-ges with [gestorfp = 0])
 set cpw/ocan (cplants with [storcan = 0])
 set ghw/ocan (grainhandlers with [storcan = 0])
 set epw/ofw (eps with [epstorfw = 0])

; show sum([gestorsw] of gewithsw)
; show sum([gestorsw] of all-ges)
; show sum([gestorbar] of all-ges)
; show sum([gestorfp] of all-ges)
; show sum([epstorfw] of eps)
; show sum([storcan] of grainhandlers)

end

to calc-truck-cost ; calculate trucking cost as a function of the Euclidean
Disitance from farmer to the grain elevator

if ticks = 0 [set truck-surcharge 10]
set truck-surcharge  truck-surcharge * (1 + ((doil-price / 100) * 1.04))
; 1.04 represents the LR elasticity from the VEC



 ask fwithsw[
 set edsw sqrt(([xcor] of self - [xcor] of fgec-sw) ^ 2 + ([ycor] of self -
[ycor] of fgec-sw) ^ 2)
 set trkdistsw sqrt((yfactor * ([ycor] of self - [ycor] of fgec-sw)) ^ 2 +
((xfactor) ^ 2) * (((edsw) ^ 2)-(([ycor] of self - [ycor] of fgec-sw) ^ 2)))
 set truckcostsw  (7.99592636077614 + trkdistsw * (0.061872896)) * [fstorsw]
of self
 set tottruckcsw truckcostsw * (1 + (truck-surcharge / 100))]
```

```
 ask fwithcan[
 set edcan sqrt(([xcor] of self - [xcor] of fghc-can) ^ 2 + ([ycor] of self -
[ycor] of fghc-can) ^ 2)
 set trkdistcan sqrt((yfactor * ([ycor] of self - [ycor] of fghc-can)) ^ 2 +
((xfactor) ^ 2) * (((edcan) ^ 2)-(([ycor] of self - [ycor] of fghc-can) ^
2)))
 set truckcostcan  (6.66333846100087 + trkdistcan * (0.0515612610048975)) *
[fstorcan] of self
 set tottruckccan truckcostcan * (1 + (truck-surcharge / 100))]

 ask fwithfw[
 set edfw sqrt(([xcor] of self - [xcor] of fepc-fw) ^ 2 + ([ycor] of self -
[ycor] of fepc-fw) ^ 2)
 set trkdistfw sqrt((yfactor * ([ycor] of self - [ycor] of fepc-fw)) ^ 2 +
((xfactor) ^ 2) * (((edfw) ^ 2)-(([ycor] of self - [ycor] of fepc-fw) ^ 2)))
 set truckcostfw  (7.99592636077614 + trkdistfw * (0.061872896)) * [fstorfw]
of self
 set tottruckcfw truckcostfw * (1 + (truck-surcharge / 100))]

 ask fwithfp[
 set edfp sqrt(([xcor] of self - [xcor] of fgec-fp) ^ 2 + ([ycor] of self -
[ycor] of fgec-fp) ^ 2)
 set trkdistfp sqrt((yfactor * ([ycor] of self - [ycor] of fgec-fp)) ^ 2 +
((xfactor) ^ 2) * (((edfp) ^ 2)-(([ycor] of self - [ycor] of fgec-fp) ^ 2)))
 set truckcostfp  (7.99592636077614 + trkdistfp * (0.061872896)) * [fstorfp]
of self
 set tottruckcfp truckcostfp * (1 + (truck-surcharge / 100))]

 ask fwithbar[
 set edbar sqrt(([xcor] of self - [xcor] of fgec-bar) ^ 2 + ([ycor] of self -
[ycor] of fgec-bar) ^ 2)
 set trkdistbar sqrt((yfactor * ([ycor] of self - [ycor] of fgec-bar)) ^ 2 +
((xfactor) ^ 2) * (((edbar) ^ 2)-(([ycor] of self - [ycor] of fgec-bar) ^
2)))
 set truckcostbar  (6.39668886179948 + trkdistbar * (0.049497912480469)) *
[fstorbar] of self
 set tottruckcbar truckcostbar * (1 + (truck-surcharge / 100))]


end



to move-to-ports


ask all-ges
  [set VCswqty gestorsw * 0.429
   set TBswqty gestorsw * 0.224
   set domswqty gestorsw * 0.347


   set VCbarqty gestorbar * 0.185
   set TBbarqty gestorbar * 0.025
   set dombarqty gestorbar * 0.79


   set VCfpqty gestorfp * 0.739
   set TBfpqty gestorfp * 0.06
   set domfpqty gestorfp * 0.201
   ]

  ask all-ges
  [set VCcanqty storcan * 0.892531876
```

```
   set TBcanqty storcan * 0.107468124
      ]

  ask cplants
  [set VCcanqty storcan * 0.49
   set TBcanqty storcan * 0.059
   set bdcanqty storcan * 0.451]




set SWVCsupply sum([VCswqty] of all-ges)
set SWTBsupply sum([TBswqty] of all-ges)
set swdomsupply sum([domswqty] of all-ges)

set BARVCsupply sum([VCbarqty] of all-ges)
set BARTBsupply sum([TBbarqty] of all-ges)
set bardomsupply sum([dombarqty] of all-ges)

set fpVCsupply sum([VCfpqty] of all-ges)
set fpTBsupply sum([TBfpqty] of all-ges)
set fpdomsupply sum([domfpqty] of all-ges)

set CANVCsupply sum([VCcanqty] of grainhandlers)
set CANTBsupply sum([TBcanqty] of grainhandlers)
set CANBDsupply sum([BDcanqty] of cplants)


;;; Ask Ethanol Plants to process Grain and Move Excess Supply to Port ;;;

set tot-exp-ethsupply 0

if total-fw-production != 0[
ifelse year = 2010
[set gasoline-demand 2560526000]                                     ; 2010
Sales of Sask. Gasoline in Litres
[set gasoline-demand (-7.83E+07 + (40050.67143 * year)) * 1000]        ;
Saskatchewan Trend Regression of future gasoline demand

set ethanol_demand (ethanol_mandate / 100) * gasoline-demand

ask eps
[set ethproduct (epstorfw * 371.7472119)]                             ;
Wheat Grain Conversion Factor Derived from Dept. of food and Agriculture
Govt. Western Australia May 2006

set ethsupply sum([ethproduct] of eps)



set total-dom-ethdemand ethanol_demand                               ; Set
domestic demand that will be supplied by the ethanol plants
set nsgreatd (count(eps with[ethproduct > meanethdemand]))

;Allocating Supply to domestic demand and/or Export Supply
set meanethdemand (ethanol_demand / count(eps with [epstorfw > 0]))
ifelse ethsupply >= ethanol_demand
[ask eps with [ethproduct <= (meanethdemand)]
    [set dom-ethsupply ethproduct
     set exp-ethsupply 0
     set total-dom-ethdemand total-dom-ethdemand - ethproduct]
 ask eps with [ethproduct > (meanethdemand)]
```

```
    [set dom-ethsupply total-dom-ethdemand / (count(eps with[ethproduct >
meanethdemand]))]

 ask eps with [ethproduct > (meanethdemand)]
    [set total-dom-ethdemand total-dom-ethdemand - dom-ethsupply
     set exp-ethsupply ethproduct - dom-ethsupply]]

[ifelse total-fw-production = 0
  [ask eps
    [set dom-ethsupply 0
     set exp-ethsupply 0]]
  [Ask eps
    [set dom-ethsupply ethproduct
     set exp-ethsupply 0 ]]]

 set tot-exp-ethsupply sum([exp-ethsupply] of eps)]


;; Ask Biodiesel Plant to process Canola and Move Excess Supply to Port ;;

ifelse year = 2010
; 2010 Sales of Sask. Gasoline in Litres
[set diesel-demand 2447498000]
; Trend Regression of future gasoline demand
[set diesel-demand (-113470246.18  + (57558.72987 * year)) * 1000]

set biodiesel_demand (biodiesel_mandate / 100) * diesel-demand

ask bds
[set bdproduct (canbdsupply * 1083.818759)]
; Canola coversion factor of 1083.82 computed from data collected from FAPRI
Missouri

set Biodsupply sum([bdproduct] of bds)


;Allocating Supply to domestic demand and/or Export Supply
ifelse Biodsupply >= biodiesel_demand
[ask bds
   [set dom-Biodsupply biodiesel_demand
    set exp-Biodsupply Biodsupply - biodiesel_demand
    ]]

[ifelse total-can-production = 0
  [ask bds
    [set dom-Biodsupply 0
     set exp-Biodsupply 0]]
  [Ask Bds
    [set dom-Biodsupply bdproduct
     set exp-Biodsupply 0 ]]]

 set tot-exp-Biodsupply sum([exp-Biodsupply] of bds)
end



to calc-railcost
set rail-surcharge truck-surcharge

Ask all-ges
[set swrailcVC round((VCswqty) * (railcost * 0.02097) * distvc / 1.609344) *
(1 + (rail-surcharge / 100))
 set swrailcTB round((TBswqty) * (railcost * 0.02097)  * distTB / 1.609344) *
(1 + (rail-surcharge / 100))
```

```
 set barrailcVC round((VCbarqty) * (railcost * 0.02097) * distvc / 1.609344)
* (1 + (rail-surcharge / 100))
 set barrailcTB round((TBbarqty) * (railcost * 0.02097) * distTB / 1.609344)
* (1 + (rail-surcharge / 100))


 set fprailcVC round((VCfpqty) * (railcost * 0.02097) * distvc / 1.609344) *
(1 + (rail-surcharge / 100))
 set fprailcTB round((TBfpqty) * (railcost * 0.02097) * distTB / 1.609344) *
(1 + (rail-surcharge / 100))


 set swtotrcost swrailcVC + swrailcTB
 set bartotrcost barrailcVC + barrailcTB
 set fptotrcost fprailcVC + fprailcTB

]
ask grainhandlers
[set canrailcVC round((VCcanqty) * (railcost * 0.02097) * distvc / 1.609344)
* (1 + (rail-surcharge / 100))
 set canrailcTB round((TBcanqty) * (railcost * 0.02097) * distTB / 1.609344)
* (1 + (rail-surcharge / 100))
 set cantotrcost canrailcVC + canrailcTB]


ask cplants
 [set canrailcBD round((BDcanqty) * (railcost * 0.02097) * distBD / 1.609344)
* (1 + (rail-surcharge / 100))
  set cantotrcost  cantotrcost + canrailcBD]

ask bds
 [set canrailcVC round(((exp-biodsupply * 0.000885)) * (railcost * 0.02097) *
distVC / 1.609344) * (1 + (rail-surcharge / 100)) ; Biodiesel litres is
converted back to MT to calculate rail cost to VC
  set cantotrcost  canrailcVC]

ifelse total-fw-production = 0
[ask eps
 [set ethrailc 0
  set ethtotrcost  ethrailc]]
[ask eps
 [ifelse ethproduct = 0
 [set ethrailc 0
  set ethtotrcost  ethrailc]
 [set ethrailc round(((exp-ethsupply * 0.0007892)) * (railcost * 0.02097) *
distVC / 1.609344) * (1 + (rail-surcharge / 100))       ; ethanol litres is
converted back to MT to calculate rail cost to VC
  set ethtotrcost  ethrailc]]]


 ask fwithsw[set railcostsw (fstorsw / [gestorsw] of fgec-sw) * [swtotrcost]
of fgec-sw]
 ask fwithbar[set railcostbar (fstorbar / [gestorbar] of fgec-bar) *
[bartotrcost] of fgec-bar]
 ask fwithfp[set railcostfp (fstorfp / [gestorfp] of fgec-fp) * [fptotrcost]
of fgec-fp]
 ask fwithcan[
   ifelse [breed] of fghc-can !=  cplants
   [set railcostcan (fstorcan / [storcan] of fghc-can) * [cantotrcost] of
fghc-can]
```

```
   [set railcostcan (fstorcan / [storcan] of fghc-can) * ([cantotrcost] of
fghc-can + ([bdcanqty] of fghc-can / canbdsupply) * [cantotrcost] of bd
37139)]]


 ask fwithfw[set railcostfw (fstorfw / [epstorfw] of fepc-fw) * [ethtotrcost]
of fepc-fw]

;show "Computation of Rail Cost Complete"

end



to ocean-freight
Ask farmers[
  set OFCsw 0
  set OFCbar 0
  set OFCfp 0
  set OFCfw 0
  set OFCcan 0]
Ask all-ges[
  set ofcostsw 0
  set ofcostbar 0
  set ofcostfp 0
  set ofcostcan 0]
Ask cplants[
  set ofcostcan 0]
Ask bds[
  set ofcostcan 0]
ask eps[
  set ofcostfw 0]


if OceanFreight[
 ifelse ticks = 0[
   set OFReast  19.67
   set OFRwest  26.38
   ask all-ges[
     set ofcostsw OFRwest * vcswqty + OFReast * tbswqty
     set ofcostbar OFRwest * vcbarqty + OFReast * tbbarqty
     set ofcostcan OFRwest * vccanqty + OFReast * tbcanqty
     set ofcostfp OFRwest * vcfpqty + OFReast * tbfpqty]

   ask bds[
     set ofcostcan exp-biodsupply * 0.000885 * OFRwest]
   ask cplants[
     set ofcostcan (([ofcostcan] of bd 37139) * [bdcanqty] of self /
canbdsupply) + vccanqty * OFRwest + tbcanqty * OFReast]
   ask eps[
     set ofcostfw exp-ethsupply * 0.0007892 * OFRwest]

   ask fwithsw[
     set OFCsw fstorsw / [gestorsw] of fgec-sw * [ofcostsw] of fgec-sw]
   ask fwithbar[
     set OFCbar fstorbar / [gestorbar] of fgec-bar * [ofcostbar] of fgec-bar]
   ask fwithfp[
     set OFCfp fstorfp / [gestorfp] of fgec-fp * [ofcostfp] of fgec-fp]
   ask fwithfw[
     set OFCfw fstorfw / [epstorfw] of fepc-fw * [ofcostfw] of fepc-fw]
   ask fwithcan[
     set OFCcan fstorcan / [storcan] of fghc-can * [ofcostcan] of fghc-can]]
```

```
[
   set OFReast  OFReast *( 1 + (0.337 * (doil-price / 100)))   ;Growth
elasticity obtained from Hummels (2007), Initital values obtained as estimate
Canadian Grain Exports 2010/11
   set OFRwest  OFRwest *( 1 + (0.337 * (doil-price / 100)))
   ask all-ges[
     set ofcostsw OFRwest * vcswqty + OFReast * tbswqty
     set ofcostbar OFRwest * vcbarqty + OFReast * tbbarqty
     set ofcostcan OFRwest * vccanqty + OFReast * tbcanqty
     set ofcostfp OFRwest * vcfpqty + OFReast * tbfpqty]

   ask bds[
     set ofcostcan exp-biodsupply * 0.000885 * OFRwest]
   ask cplants[
     set ofcostcan (([ofcostcan] of bd 37139) * [bdcanqty] of self /
canbdsupply) + vccanqty * OFRwest + tbcanqty * OFReast]
   ask eps[
     set ofcostfw exp-ethsupply * 0.0007892 * OFRwest]

   ask fwithsw[
     set OFCsw fstorsw / [gestorsw] of fgec-sw * [ofcostsw] of fgec-sw]
   ask fwithbar[
     set OFCbar fstorbar / [gestorbar] of fgec-bar * [ofcostbar] of fgec-bar]
   ask fwithfp[
     set OFCfp fstorfp / [gestorfp] of fgec-fp * [ofcostfp] of fgec-fp]
   ask fwithfw[
     set OFCfw fstorfw / [epstorfw] of fepc-fw * [ofcostfw] of fepc-fw]
   ask fwithcan[
     set OFCcan fstorcan / [storcan] of fghc-can * [ofcostcan] of fghc-can]]
]
end



to price-react

;;;;;;;;;;;;;; Price Reaction For Bioethanol Crops;;;;;;;;;;;;;;;;;;;;;


set pgast (42.23218 + 0.562963 * crude-price)/ 100
; Gas price per litre method extracted from Tyner & Taheripour 2007. Used VEC
and Regina Gas and Cdn Oilprice per barrel for estimation
set petht ((0.625  * pgast) + (eth-subsidy / 100)) * (1 - (ethprofit / 100))
; Ethanol Price is 70% but use 62.5% (pimentel(2003) of the Gas price (Tyner
& Taheripour 2007) and calibrated to obtain reasonable ethanol price stimates


ifelse ticks = 0
[set epmargin 0.30]
; Rilett 2003= 0.60-0.70+ (assumed $0.75)grown at PPI rate of 9.5% (2002-
2010)= ($0.82125) with assumed 36% accrued to Non feedstock costs= approx.
$0.30/L
[set epmargin epmargin + (0.2 *(0.75 * (doil-price / 100)))]
set fethp (petht - epmargin)
set pfwt fethp * 371.7472119


;;;;;;;;;;;;;;;;;; Price Reaction For Biodiesel Crops ;;;;;;;;;;;;;;;;;


set pdt (33.14212 + 0.51646 * crude-price)/ 100
;
```

```
set pbdt ((0.9 * pdt) + (Bd-subsidy / 100)) * (1 - (ethprofit / 100))
;BioDiesel Price is 90% of the Diesel price Dept. of food and Agriculture
Govt. Western Australia May 2006


ifelse ticks = 0
[set bdmargin 0.66]
[set bdmargin bdmargin + (0.14 * (0.75 * (doil-price / 100)))]
set fbdp (pbdt - bdmargin)
set pbdcant fbdp * 1083.818759

set pcanenergy (pbdcant * sum([bdcanqty] of cplants) + wpcan *
(sum([vccanqty] of cplants) + sum([tbcanqty] of cplants))) / sum([storcan] of
cplants)
set pcanfood wpcan
end

to set-tax-exemptions
ifelse scenset = 1 or scenset = 2
 [ifelse year = 2010
  [set eth-subsidy 25
   set bd-subsidy 39]
  [ifelse year = 2011
   [set eth-subsidy 24
    set bd-subsidy 35]
   [ifelse year = 2012
    [set eth-subsidy 23
     set bd-subsidy 33]
    [ifelse year = 2013
     [set eth-subsidy 22
      set bd-subsidy 29]
     [ifelse year = 2014
      [set eth-subsidy 21
       set bd-subsidy 25]
      [ifelse year = 2015
       [set eth-subsidy 20
        set bd-subsidy 23]
       [ifelse year = 2016
        [set eth-subsidy 19
         set bd-subsidy 21]
        [ifelse year = 2017
         [set eth-subsidy 18
          set bd-subsidy 19]
         [set eth-subsidy 18
          set bd-subsidy 21]]]]]]]]]
  [set eth-subsidy 25
   set bd-subsidy 39]
end


to calc-margin


  ask farmers
  [set fgpsw  0
   set fgpcan  0
   set fgpbar  0
   set fgpfp 0
   set fgpfw  0]


  ifelse ticks = 0
  [ask farmers
   [set fwcmemory (tottruckcsw + copsw) / (fstorsw)
```

```
    set swcmemory (tottruckcsw + basiscostsw + railcostsw + copsw + OFCsw) /
(fstorsw)]]
  [ask farmers
    [if fstorsw > 0
      [set swcmemory (tottruckcsw + basiscostsw + railcostsw + copsw + OFCsw)
/ (fstorsw)]
     if fstorfw > 0
      [set fwcmemory (tottruckcfw + railcostfw + copfw + OFCfw) /
(fstorfw)]]]


  ask farmers
  [ifelse fstorsw = 0
   [set fgpsw wpsw - swcmemory
    set vcsw swcmemory]
   [set fgpsw ((wpsw * fstorsw) - tottruckcsw - basiscostsw - railcostsw -
copsw - OFCsw) / (fstorsw)
    set vcsw (tottruckcsw + basiscostsw + railcostsw + copsw + OFCsw) /
fstorsw]


   set fgpbar ((wpbar * fstorbar) - tottruckcbar - basiscostbar - railcostbar
- copbar - OFCbar) / (fstorbar)
   set vcbar (tottruckcbar + basiscostbar + railcostbar + copbar + OFCbar) /
(fstorbar)


   set fgpfp ((wpfp * fstorfp) - tottruckcfp - basiscostfp - railcostfp -
copfp - OFCfp) / (fstorfp)
   set vcfp (tottruckcfp + basiscostfp + railcostfp + copfp + OFCfp) /
(fstorfp)

   ifelse fstorfw = 0
   [set fgpfw pfwt - fwcmemory
    set vcfw fwcmemory]
   [set fgpfw ((pfwt * fstorfw) - tottruckcfw - copfw - railcostfw - OFCfw) /
(fstorfw)
    set vcfw  (tottruckcfw + copfw + railcostfw + OFCfw) / (fstorfw)]


   ifelse [breed] of fghc-can =  cplants
     [set fgpcan ((pcanenergy * fstorcan) - tottruckccan - railcostcan -
copcan - basiscostcan - OFCcan) / (fstorcan)
      set vccan (tottruckccan - railcostcan - copcan - basiscostcan - OFCcan)
/ (fstorcan)]
     [set fgpcan ((pcanfood * fstorcan) - tottruckccan - railcostcan - copcan
- basiscostcan - OFCcan) / (fstorcan)
      set vccan (tottruckccan - railcostcan - copcan - basiscostcan - OFCcan)
/ (fstorcan)]
]
set Biod-fgpcan sum([fgpcan] of farmers with[[breed] of fghc-can = cplants])
/ count(farmers with[[breed] of fghc-can = cplants])

;Show "Computation of Margin Complete"
 end



to calc-means

ifelse total-sw-production = 0
[set meanrailcostSW 0
 set meantruckcostsw 0
 set meangmsw 0
```

```
 set meancopsw 0
 set meanofcsw 0]
[set meanrailcostSW sum([railcostsw] of farmers)/ total-sw-production
 set meantruckcostsw sum([tottruckcsw] of farmers)/ total-sw-production
 set meangmsw sum([fgpsw] of fwithsw) / count(fwithsw)
 set meancopsw (sum([copsw] of fwithsw) )/ total-sw-production
 set meanofcsw (sum([ofcsw] of fwithsw) )/ total-sw-production]

ifelse total-bar-production = 0
[set meanrailcostBAR 0
 set meantruckcostBAR 0
 set meangmbar 0
 set meancopbar 0
 set meanofcbar 0]
[set meanrailcostBAR sum([railcostbar] of farmers)/ total-bar-production
 set meantruckcostBAR sum([tottruckcBAR] of farmers)/ total-BAR-production
 set meangmbar sum([fgpbar] of fwithbar) / count(fwithbar)
 set meancopbar (sum([copbar] of fwithbar) )/ total-bar-production
 set meanofcbar (sum([ofcbar] of fwithbar) )/ total-bar-production]

ifelse total-can-production = 0
[set meanrailcostCAN 0
 set meantruckcostCAN 0
 set meangmcan 0
 set meancopcan 0
 set meanofccan 0]
[set meanrailcostCAN sum([railcostcan] of farmers)/ total-can-production
 set meantruckcostCAN sum([tottruckcCAN] of farmers)/ total-can-production
 set meangmcan sum([fgpcan] of fwithcan) / count(fwithcan)
 set meancopcan (sum([copcan] of fwithcan) )/ total-can-production
 set meanofccan (sum([ofccan] of fwithcan) )/ total-can-production]

ifelse total-fp-production = 0
[set meanrailcostFP 0
 set meantruckcostFP 0
 set meangmfp 0
 set meancopfp 0
 set meanofcfp 0]
[set meanrailcostFP sum([railcostfp] of farmers)/ total-fp-production
 set meantruckcostFP sum([truckcostFP] of farmers)/ total-fp-production
 set meangmfp sum([fgpfp] of fwithfp) / count(fwithfp)
 set meancopfp (sum([copfp] of fwithfp) )/ total-fp-production
 set meanofcfp (sum([ofcfp] of fwithfp) )/ total-fp-production]


ifelse total-fw-production = 0
[set meanrailcostfw 0
 set meantruckcostfw 0
 set meangmfw 0
 set meancopfw 0
 set meanofcfw 0]
[set meanrailcostfw sum([railcostfw] of farmers)/ total-fp-production
 set meantruckcostfw sum([tottruckcfw] of farmers)/ total-fw-production
 set meangmfw sum([fgpfw] of fwithfw) / count(fwithfw)
 set meancopfw (sum([copfw] of fwithfw) )/ total-fw-production
 set meanofcfw (sum([ofcfw] of fwithfw) )/ total-fw-production]

 set meangebasissw (sum([basissw] of All-ges) )/ count(all-ges)
 set meangebasisfp (sum([basisfp] of All-ges) )/ count(all-ges)
 set meangebasisbar (sum([basisbar] of All-ges) )/ count(all-ges)
 set meangebasiscan (sum([basiscan] of All-ges) )/ count(all-ges)
```

```
end

to do-plots

  set-current-plot "Crop Production"
  set-current-plot-pen "SW"
  plot total-sw-production
  set-current-plot-pen "CAN"
  plot total-can-production
  set-current-plot-pen "FW"
  plot total-fw-production
  set-current-plot-pen "FP"
  plot total-fp-production
  set-current-plot-pen "BAR"
  plot total-bar-production


  set-current-plot "Average Gross Margins of Farmers"
  set-current-plot-pen "PSW"
  plot meangmsw
  set-current-plot-pen "PCAN"
  plot meangmcan
  set-current-plot-pen "PFW"
  plot meangmfw
  set-current-plot-pen "PFP"
  plot meangmfp
  set-current-plot-pen "PBAR"
  plot meangmbar


  set-current-plot "Average Rail Costs $/M.T."
  set-current-plot-pen "SW"
  plot meanrailcostSW
  set-current-plot-pen "CAN"
  plot meanrailcostcan
  set-current-plot-pen "FP"
  plot meanrailcostfp
  set-current-plot-pen "BAR"
  plot meanrailcostbar
  set-current-plot-pen "FW"
  plot meanrailcostfw

  set-current-plot "Average Trucking Costs $/M.T."
  set-current-plot-pen "SW"
  plot meantruckcostsw
  set-current-plot-pen "CAN"
  plot meantruckcostcan
  set-current-plot-pen "FP"
  plot meantruckcostfp
  set-current-plot-pen "BAR"
  plot meantruckcostbar
  set-current-plot-pen "FW"
  plot meantruckcostfw

  set-current-plot "Average Transpotation Costs $/M.T."
  set-current-plot-pen "SW"
  plot meantruckcostsw + meanrailcostSW + meanofcsw
  set-current-plot-pen "CAN"
  plot meantruckcostcan + meanrailcostcan + meanofccan
  set-current-plot-pen "FP"
  plot meantruckcostfp + meanrailcostfp + meanofcfp
  set-current-plot-pen "BAR"
  plot meantruckcostbar + meanrailcostbar + meanofcbar
  set-current-plot-pen "FW"
```

```
  plot meantruckcostfw + meanrailcostfw + meanofcfw

  set-current-plot "Average Basis Cost $/M.T."
  set-current-plot-pen "SW"
  plot meangebasissw
  set-current-plot-pen "FP"
  plot meangebasisfp
  set-current-plot-pen "BAR"
  plot meangebasisbar
  set-current-plot-pen "CAN"
  plot meangebasiscan



  set-current-plot "Average Production Cost $/M.T."
  set-current-plot-pen "SW"
  plot meancopsw
  set-current-plot-pen "FP"
  plot meancopfp
  set-current-plot-pen "BAR"
  plot meancopbar
  set-current-plot-pen "CAN"
  plot meancopcan
   set-current-plot-pen "FW"
  plot meancopfw

end





to output-vars

ifelse ticks = 0
[set gebswlist (list meangebasissw)
 set gebfplist (list meangebasisfp)
 set gebbarlist (list meangebasisbar)
 set gebcanlist (list meangebasiscan)
 set ngelist (list count(all-ges))]
[set gebswlist lput meangebasissw gebswlist
 set gebfplist lput meangebasisfp gebfplist
 set gebbarlist lput meangebasisbar gebbarlist
 set gebcanlist lput meangebasiscan gebcanlist
 set ngelist (lput count(all-ges) ngelist)]


if ticks = (20 - 1)
[set avgebasissw sum(gebswlist) / length(gebswlist)
 set avgebasisfp sum(gebfplist) / length(gebfplist)
 set avgebasisbar sum(gebbarlist) / length(gebbarlist)
 set avgebasiscan sum(gebcanlist) / length(gebcanlist)
]





ifelse ticks = 0
[set swpricelist (list wpsw)]
[set swpricelist lput wpsw swpricelist]

ifelse ticks = 0
[set fwpricelist (list pfwt)]
```

```
[set fwpricelist lput pfwt fwpricelist]

ifelse ticks = 0
[set cppricelist (list crude-price)]
[set cppricelist lput crude-price cppricelist]

ifelse ticks = 0
[set swprodlist (list total-sw-production)]
[set swprodlist lput total-sw-production swprodlist]

ifelse ticks = 0
[set fwprodlist (list total-fw-production)]
[set fwprodlist lput total-fw-production fwprodlist]

if ticks = (15 - 1)[
  Output-show "Scenario:" Output-show (word "Timepath:" timepath ",seed:"
rand-seed ",Oil:"Doil-price",Esub:"eth-subsidy)
  Output-show "swprodlist:"Output-show swprodlist
  Output-show "fwprodlist:"Output-show fwprodlist
  Output-show "swpricelist:"Output-show swpricelist
  Output-show "fwpricelist:"Output-show fwpricelist
  Output-show "cppricelist:"Output-show cppricelist
  Output-show "gebswlist:"Output-show gebswlist
  Output-show "gebcanlist:"Output-show gebcanlist
  Output-show "gebbarlist:"Output-show gebbarlist
  Output-show "gebfplist:"Output-show gebfplist
  Output-show "ngelist:"Output-show ngelist
  Output-show ""
  Output-show ""]

end




to reset-vars
reset-farmers-vars
reset-ge-vars
reset-ep-vars
reset-cp-vars
end

to reset-farmers-vars
 ask farmers
 [ set railcostsw 0
   set railcostbar 0
   set railcostcan 0
   set railcostfp 0
   set railcostfw 0

   set truckcostsw 0
   set truckcostbar 0
   set truckcostcan 0
   set truckcostfp 0
   set truckcostfw 0

   set tottruckcsw 0
   set tottruckcbar 0
   set tottruckccan 0
   set tottruckcfp 0
   set tottruckcfw 0
   ]

 end
```

```
to reset-ge-vars
ask all-ges
 [set gestorsw 0
  set gestorbar 0
  set gestorfp 0]
end
to reset-cp-vars
ask grainhandlers
 [set storcan 0]
end

to reset-ep-vars
ask eps
 [set epstorfw 0]
end



to setup-var-next-period






end




to go
  if ticks = 0
  [scenario1]

  if ticks = 15
  [stop
   scenario1]
  if ticks = 4
  [scenarioset]
  set-world-prices
  set-tax-exemptions
  produce
  srchntruck
  move-to-ports
  calc-railcost
  ocean-freight
  price-react
  calc-margin
  calc-means
  do-plots
  setup-var-next-period
  output-vars
   tick
   go
end

to get-fwfarmers
  ask farmers with [fstorfw > 0] [set color orange]
end

to get-biodfarmers
  ask farmers with[[breed] of fghc-can = cplants][set color green]
```

```
  ask farmers with [fstorcan = 0][set color blue]
end

to reset-farmers
  ask farmers[set color blue]
  ask patches[ set pcolor white]
end

to show-ge-close-buffer
  ask all-ges[ask patches in-radius close[set pcolor yellow]]
end


to seedtime1
set rand-seed 100
set timepath 1
set Doil-price 0
set scenset 1
setup
end

to seedtime2-4
set rand-seed 100
set timepath 1
set Doil-price 0
setup
end


to scenarioset
ifelse scenset = 1
[scenario1]
[ifelse scenset = 2
 [scenario2]
 [ifelse scenset = 3
  [scenario1]
  [scenario2]]]
end



to scenario1
set Doil-price 0
end

to scenario2
set Doil-price 10
end


to replicate
 go
 set timepath timepath + 1
 ifelse timepath = 51
   [set timepath 1
    exportout
    set scenset scenset + 1]
   [reset
    replicate]

end

to doruns
 seedtime1
```

```
 replicate
 seedtime2-4
 replicate
 seedtime2-4
 replicate
 seedtime2-4
 replicate
end

to exportout
  export-output (word "data/Output/Setting_P10_S100/seed_" rand-seed
"_oil_"Doil-price"_esub_"eth-subsidy".csv")
end
```

APPENDIX D: *FARMCHAIN MODEL* TABLE OF INITIAL VALUES AND PARAMETERS

Table D1 is lists the values of structural parameters and initial values used in the *FARMCHAIN* model.

Table D1. Structural Parameter and Initial Values in the FARMCHAIN Model

Parameter	Value	Units
Crude-price	82.88	$/ barrel
Crude price to gas price elaticity	0.75	
Crude price to fertilizer price elaticity	0.33	
Canola cushing plant margin	10	$/t
Crude price to trucking surcharge elasticity	1.04	
Crude price to trucking surcharge elasticity	1.04	
Trucking Cost intercept for hard wheat	8	$/t
Trucking Cost intercept for hard wheat	0.06	$/t per kilometre
Trucking Cost intercept for canola	6.67	$/t
Trucking Cost intercept for canola	0.05	$/t per kilometre
Trucking Cost intercept for soft wheat	8	$/t
Trucking Cost intercept for soft wheat	0.06	$/t per kilometre
Trucking Cost intercept for field peas	8	$/t
Trucking Cost intercept for field peas	0.06	$/t per kilometre
Trucking Cost intercept for barley	6.4	$/t
Trucking Cost intercept for barley	0.05	$/t per kilometre
Proportion of wheat crop through Vancouver	42.9	percent
Proportion of wheat crop through Thunder Bay	22.4	percent
Proportion of wheat crop domestic disappearance	34.7	percent
Proportion of barley crop through Vancouver	18.5	percent
Proportion of barley crop through Thunder Bay	2.5	percent
Proportion of barley crop domestic disappearance	79	percent
Proportion of field peas crop through Vancouver	73.9	percent
Proportion of field peas crop through Thunder Bay	6	percent
Proportion of field peas crop domestic disappearance	20.1	percent
Proportion of canola crop from elevators through Vancouver	89	percent
Proportion of canola crop from elevators through Thunder Bay	11	percent
Proportion of canola oil from crushing plants through Vancouver	49	percent
Proportion of canola oil from crushing plants through Thunder Bay	5.9	percent
Proportion of canola oil from crushing plants to the biodiesel plant	45	percent

Table D1. Structural Parameter and Initial Values in the FARMCHAIN Model

Parameter	Value	Units
Initial Gasoline Demand	2.6	billion litres
Gasoline demand trend regression intercept	-78	billion litres
Gasoline demand trend regression slope	40	million litres/year
Ethanol Mandate	7.5	percent
Conversion factor of wheat in Tonnes to ethanol in litres	371	
Initial Diesel Demand	2.4	billion litres
Diesel demand trend regression intercept	-113	billion litres
Diesel demand trend regression slope	58	million litres/year
biodiesel Mandate	2	percent
Conversion factor of canola in Tonnes to biodiesel in litres	1084	
Rail cost	0.02	$/ tonne-mile
Rail cost conversion into $ per tonne-kilometer	1.61	
Weight of a litre of biodiesel	0.00089	Tonnes
Weight of a litre of ethanol	0.00079	Tonnes
Initial ocean freight rate westbound	26.38	$/t
Initial ocean freight rate eastbound	19.67	$/t
Crude price to ocean freight rate elasticity	0.337	
Gas Price on crude oil price regression intercept	42.2	¢/litre
Gas Price on crude oil price regression slope per dollar of cude oil price	0.56	¢/litre
Proportion of ethanol cost of production that varies with fuel prices	20	percent
Initial ethanol producers' margin	30	¢/litre
Ethanol fuel equivalence factor	62.5	percent
Returns on biofuel (ethanol and Biodiesel) plant investment (ethprofit)	17.5	percent
Diesel Price on crude oil price regression intercept	33.14	¢/litre
Diesel Price on crude oil price regression slope per dollar of cude oil price	0.52	¢/litre
Proportion of biodiesel cost of production that varies with fuel prices	0.14	
Ethanol fuel equivalence factor	90	percent
Initial biodiesel producer's margin	66	¢/litre

Source: Created by author with data from the *FARMCHAIN* model.